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# THE GEOLOGY OF THE DEDDICK–WULGULMERANG AREA, EAST GIPPSLAND

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## Abstract

The Snowy River Volcanics of Lower Devonian age consisting mainly of rhyodacites together with smaller amounts of pyroclastics and latites rest unconformably upon a basement of folded Upper Ordovician sediments intruded by granodiorite. In the western portion of the area, the volcanics reach a thickness of over 10,000 feet and are folded into a large syncline striking north-south. The extrusion of the rhyodacites is closely connected with an extensive arcuate fracture. Subsidence of the basement rock has occurred south of the fracture simultaneously with extrusion of rhyodacites, resulting in the accumulation of great thicknesses of rhyodacites and pyroclastics in the depression made by the downthrown block.

Epi Middle Devonian lamprophyre dykes intrude the granodiorite and also the rhyodacites. Mineralization resulting in the formation of galena deposits occurs in the downthrown block of the granodiorite close to the main fracture, and is closely associated with the lamprophyre dykes which are parallel to the main fracture.

## Table of Contents

INTRODUCTION
PREVIOUS WORK
PHYSIOGRAPHY
GENERAL GEOLOGY
    Upper Ordovician
    Silurian
        *Granodiorite*
            Xenoliths
            Age of Granodiorite
    Lower Devonian
        *Deddick Rhyodacite*
        *Black Mountain Rhyodacite*
        *Gelantipy Rhyodacite*
        *Intercalated Minor Rhyodacites*
        *Latites and Quartz Latites*
        *Sedimentary Rocks*
        *Dykes*
    Structural Relations of the Snowy River Volcanics
        *Mechanics of Extrusion*
        *Formation of Turnback Fault*
    Petrogenesis
    Epi Middle Devonian
        *Biotite Monchiquite*
        *Petrogenesis*
        *Spessartites*
        *Mineral Deposits*
            General
            Wall Rock Alteration
            Paragenesis
            Temperature of Deposition
            Relations of Lodes and Dykes

Regional Metamorphism of Galena
Oxidation
Mineral Zoning
Economic Possibilities
STRUCTURAL RELATIONS OF LODES AND DYKES
CAINOZOIC
*Fluviatile Deposits*
*Newer Basalt*
ACKNOWLEDGEMENTS
BIBLIOGRAPHY

## Introduction

An area of about 18 by 10 miles covering portions of the parishes of Woongulmerang East, Woongulmerang West, Deddick and Chilpin is dealt with in this paper. Because of the rugged and inaccessible nature of the terrain some of the mapping is best classed as reconnaissance. However, key areas along both sides of the granodiorite-rhyodacite contacts in the central part of the area, together with most of the Wulgulmerang plateau, have been mapped in more detail. Reconnaissance mapping has been carried out mainly in the eastern and western extremities of the region and has been limited mainly to delineating the three major flows of rhyodacite. Mapping of this kind is indicated by broken lines, more accurate mapping by full lines.

## Previous Work

The only important contributions to the geology of this area have been made by Howitt (1876, 1878) and Ferguson (1899). Howitt made a traverse down part of the Little River Gorge. He came to the conclusion that the contact of granodiorite and rhyodacite at Little River was a fault of considerable displacement, extending through to Suggan Buggan. He subdivided the "Snowy River Porphyries" into a basal series of massive quartz porphyries and felsites and an upper series of fragmentary rocks, mainly tuffs and agglomerates.

In 1899 Ferguson published his report on the geology of the Mt. Deddick silver-lead field, together with a map. This report dealt principally with the mining geology of the area, and only briefly with the general geology. However, Ferguson recognized most of the major features of the general geology. He differed from Howitt regarding the existence of a fault at the rhyodacite-granodiorite contact on the Little River.

Jenkins (1899), Sterling (1899), Dunn (1909) and Whitelaw (1921) have contributed short reports mainly on the galena deposits, but they have added little to the work of Howitt and Ferguson. Reports on neighbouring districts which have some bearing upon the area in question have been published by Crohn (1949) for the Omeo District, Teale (1920), Cochrane and Samson (1947) for the Nowa Nowa-South Buchan district, and Gaskin (1943) for Bindi. Gaskin has also mapped the Buchan area, but has not yet published his results.

## Physiography

The major feature of the physiography of the area is the youthful dissection of an elevated peneplain by the Snowy River and its tributaries. The peneplain lies at a height of about 2,500-3,000 ft. and slopes gently towards the south. On the west side of the Snowy River in the Wulgulmerang area, much of the peneplain is covered by basalt. On physiographical grounds, Hills (1938) has suggested that this basalt belongs to the Newer Basalt Series, and consequently the uplift and subsequent

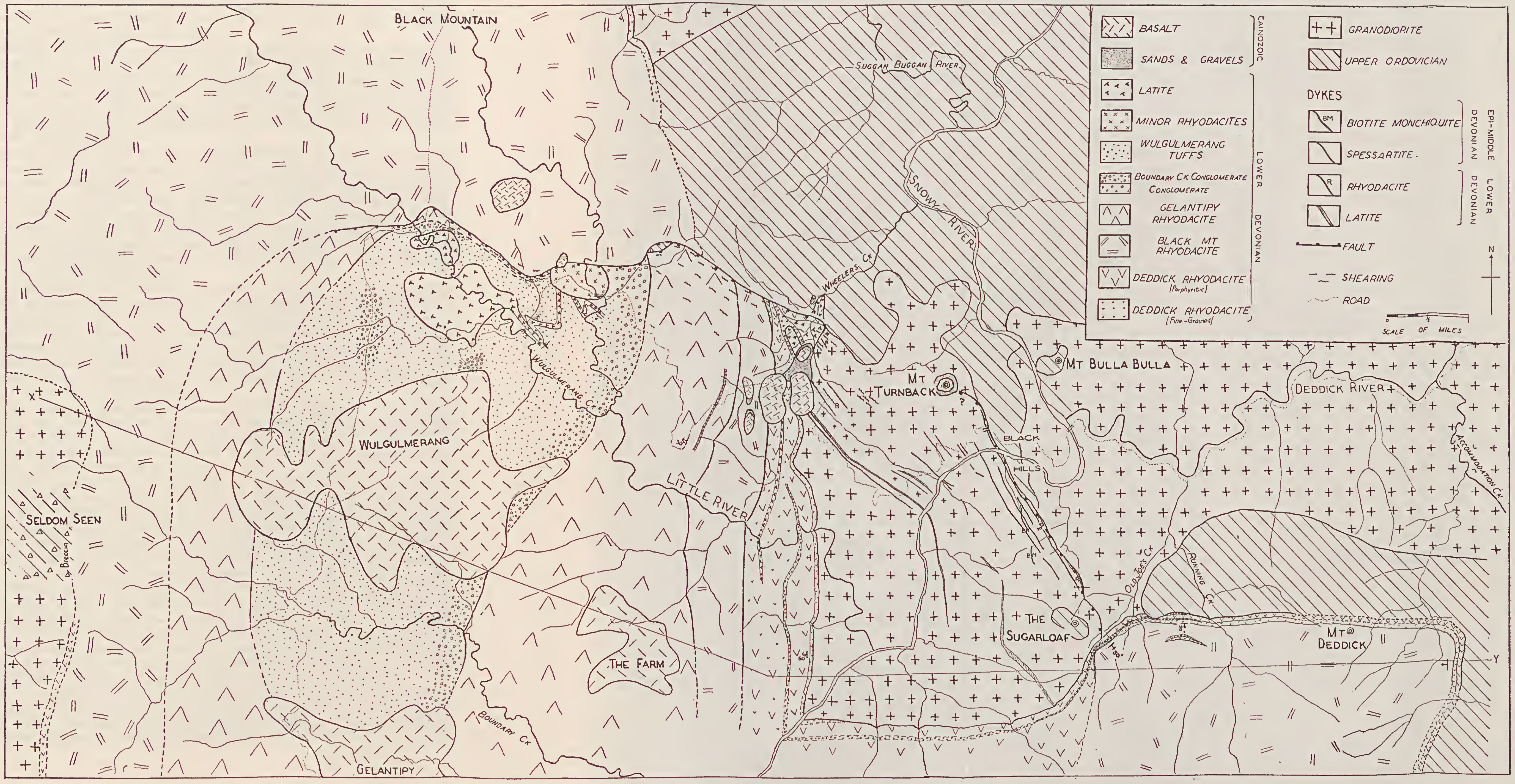
BLACK MOUNTAIN
SUGGAN BUGGAN RIVER
SNOWY RIVER
WHEELERS CK
WULGULMERANG CK
WULGULMERANG
LITTLE RIVER
MT TURNBACK
MT BULLA BULLA
DEDDICK RIVER
ACCOMMODATION CK
BLACK HILLS
RUNNING CK
OLD JOES CK
THE SUGARLOAF
MT DEDDICK
THE FARM
BOUNDARY CK
GELANTIPY
SELDOM SEEN
Breccia
X
Y
BASALT
SANDS & GRAVELS
CAINOZOIC
LATITE
MINOR RHYODACITES
WULGULMERANG TUFFS
BOUNDARY CK CONGLOMERATE CONGLOMERATE
GELANTIPY RHYODACITE
BLACK MT RHYODACITE
DEDDICK RHYODACITE (Porphyritic)
DEDDICK RHYODACITE (Fine-Grained)
LOWER DEVONIAN
GRANODIORITE
UPPER ORDOVICIAN
DYKES
BM
BIOTITE MONCHIQUITE
SPESSARTITE
EPI-MIDDLE DEVONIAN
R
RHYODACITE
LATITE
LOWER DEVONIAN
FAULT
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Fig. 1

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erosion of the peneplain has occurred since the extrusion of Newer Basalt. In a relatively short time steep-sided valleys and gorges have been gouged out by the Snowy River, Little River, Boundary Creek, Wheelers Creek, Suggan Buggan River, Running Creek and smaller tributaries.

The topography is extremely youthful, and is largely controlled by differential erosion of granodiorite, rhyodacites and Ordovician sediments. The dissection of rhyodacites and slates has resulted in a topography extremely rugged and precipitous, possessing great scenic grandeur. The Little River, one of the principal tributaries, has cut a gorge 2,500 ft. deep, often with sheer walls. This stream falls 2,000 ft. in a distance of one mile. Wulgulmerang Creek drops into the Little River over a waterfall 1,000 ft. high.

The behaviour of rhyodacite and slate country during dissection has been very similar, although the rhyodacites tend to form more precipitous gorges. This is doubtless due to the strong jointing existing in the rhyodacites. In general, granodiorite is much more easily eroded than the rhyodacite and Ordovician, and therefore tends to occupy large topographic depressions as at Deddick, and Suggan Buggan. Consequently it is usually possible to pick up the granodiorite boundaries accurately upon aerial photographs relying solely upon topography as a criterion. Plate II shows an aerial photograph taken at 17,000 ft. of the granodiorite-rhyodacite contact near the Little River at Deddick.

The control of drainage by geological structure is not very marked within the area. There are, however, some examples. Two miles below the bridge at McKellop's Crossing a long slender tongue of Ordovician rocks protrudes into the granodiorite, striking N.N.W. Parallel to and S.W. from this tongue there has been strong and persistent fracturing and faulting in the granodiorite. This is shown by the numerous lamprophyre dykes, mineral lodes, and intense jointing, which have the same strike. These persistent fractures appear to have determined the direction of the local stream valleys, which lie parallel (Fig. 2).

Another case in which geological structure may have influenced drainage lies near the Suggan Buggan River, due east of Black Mountain (Fig. 1). Here a very marked parallel drainage pattern in Ordovician slates and sandstones lies parallel to the main granodiorite Ordovician contact. It is probable that jointing parallel to the contact may be responsible for this pattern.

The pre-basaltic peneplain may be recognized on both sides of the Snowy River, and is remarkably even, especially on the plateau lying immediately south of Mt. Deddick. It is best developed in the Wulgulmerang-Black Mountain area where it is largely intact, the relatively small amount of dissection it had undergone being indicative of relatively recent uplift. It was this reason which led Hills (1938) to place the basalt lying on top of the peneplain among the Newer Basalt Series. In this area the basalts are quite thin, rarely of greater thickness than 100 ft. Farther south near Gelantipy the pre-basaltic peneplain had suffered much more dissection before the extrusion of the basalt. This is demonstrated by the rapid variations in thickness of the basalt which obviously rests upon a very uneven surface. Although the basalt in some places reaches a thickness of 500 ft., inliers of rhyodacite outcrop through the basalt quite close to the places of maximum thickness. This indicates that dissection of the pre-basaltic peneplain, although insignificant in the Wulgulmerang area, increased towards the south where it became quite marked.

The uplift of the peneplain, following extrusion of the basalt, probably occurred during the Lower Pliocene period (Hills, 1940). Although evidence of recent faulting is lacking, it seems likely that this district has also been elevated by the Kosciusko Uplift—the Snowy Mountains and Kosciusko Plateau can be regarded as a northern

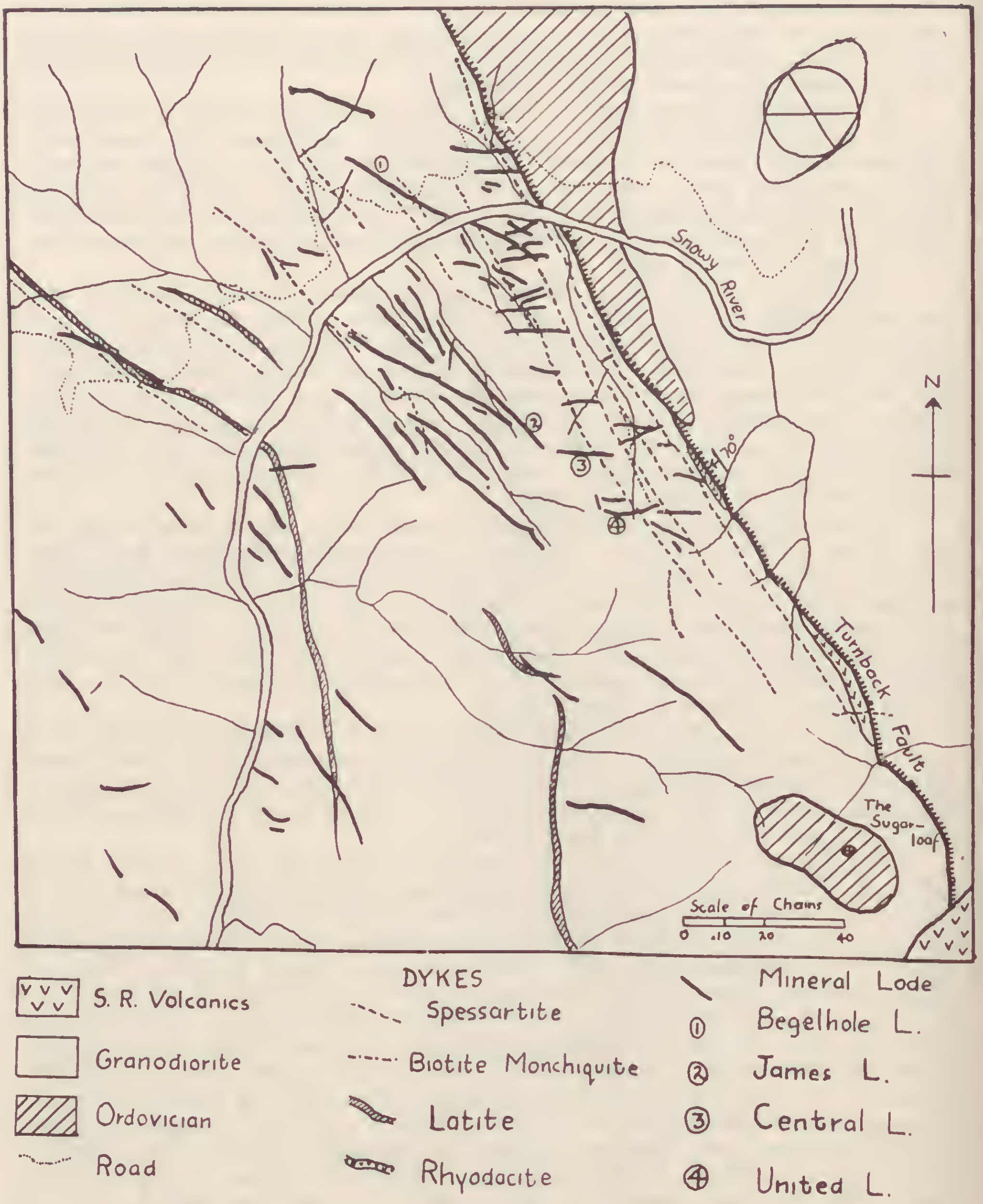

Snowy River
Turnback Fault
70°
The Sugar-loaf
N
①
②
③
④
Scale of Chains
0 10 20 40
S. R. Volcanics
Granodiorite
Ordovician
Road
DYKES
Spessartite
Biotite Monchiquite
Latite
Rhyodacite
Mineral Lode
① Begelhole L.
② James L.
③ Central L.
④ United L.

FIG. 2

extension of the tilted peneplain of the Gelantipy, Wulgulmerang and Cobberas regions.

Several patches of basalt, often underlain by river gravels, occur at heights of about 2,000 ft. in the central part of the area—notably on Mt. Turnback, "The Farm", and the head of Wheelers Creek. These basalts are 1,000 ft. lower than those at Wulgulmerang, and appear to be residuals of a formerly more extensive flow. There is no evidence to suggest that they owe their position to faulting. They probably represent remnants of a separate flow of basalt which flowed down the valley of the Snowy River whilst that valley was in an early stage of dissection. This interpretation is supported by the fact that beds of river gravels are found underneath some of these patches. River gravels do not occur under the basalt at Wulgulmerang.

## General Geology

### Upper Ordovician

Sediments of Upper Ordovician age are widespread throughout the area. The largest exposures occur upstream from the bridge at McKellops Crossing on the Snowy River. Other patches occur on the Sugarloaf, at Mt. Deddick, and in the far west near Seldom Seen Lookout. The latter occurrence is not recorded in the 8 miles to the inch Geological Survey map of Victoria.

The sediments consist of sandstones, greywackes, mudstones, shales and slates, in places carbonaceous. These have been folded in an irregular manner, the strikes not being constant. Dips average 30° to 40°, but in places they are as low as 20°, and elsewhere vertical dips are to be found. The strikes also vary, such a wide variety was met with that it is impossible to say whether there is any preferred direction. Folding of this nature is unusual in Victorian Ordovician rocks. The apparent irregularity is largely due to the high angles of pitch encountered. Near Mt. Deddick these were sometimes as high as 35°.

Graptolites found by Ferguson (1899) in some of the slates in the Deddick district were determined by Hall. They are indicative of Upper Ordovician age. Graptolites of this age have also been found by Tonner in the Accommodation Creek area near the copper mine (Hall 1912) and also by Thomas (personal communication) some distance upstream from the copper mine. The graptolites include *Dicellograptus* sp., *climacograptus,* fragments of Diplograptidae, *Dicranograptus hians, Climacograptus caudatus, Cryptograptus tricornis, Diplograptus calcaratus.*

After folding, the sediments were intruded by a batholith of granodiorite. Much of the roof of the batholith has been removed by erosion, but part remains—the Sugarloaf, for example, represents a remnant of the roof. It consists of a cone of hard metamorphosed sediments resting upon the granodiorite at an elevation of 1,800 ft. Parts of Mt. Deddick and Mt. Bulla Bulla are also remnants of the roof of the batholith, which underlies them at a shallow depth. Metamorphism of the sediments by granodiorite has resulted in the formation mainly of quartzites and quartz sericite hornfels, near the contact.

The grade of metamorphism is fairly low. A slide, No. 7726, University of Melbourne Collection, has been taken across the contact at the Black Hills, on the Snowy River. It shows a mudstone which has been partially recrystallized. Numerous spots of chloritic material and iron ore have been developed, whilst much of the finer argillaceous constituents have been recrystallized to chlorite and sericite. The granodiorite at the contact has been chilled to a quartz porphyrite, the crystals of quartz, plagioclase and altered biotite are closely packed in a very fine-grained, almost glassy groundmass. Subsequent shearing has occurred, fracturing especially the quartz phenocrysts. A banded shale, No. 7606, taken about 100 yards from the same contact, has been recrystallized into a quartz sericite hornfels. Spotting has developed in some of the bands. Although taken further from the contact, this specimen appears to have been more strongly metamorphosed than No. 7726 taken on the contact. This suggests that the initial composition of the rock, more especially its water content has been an important factor controlling the metamorphism.

Slide No. 7727 is taken from about 50 yards from the granodiorite-Ordovician contact near Mt. Deddick. The original rock was a sandstone. It has been changed to a quartzite with interlocking quartz grains. Subordinate iron ores and biotite have developed at the grain boundaries. A greywacke, No. 7608, from the Sugarloaf shows evidence of stronger metamorphism, small crystals of muscovite and chlorite have been abundantly developed.

In most places the contact effects have been limited to the production of low to medium grade hornfels. However, in one area, about three-quarters of a mile north of the Sugarloaf, the contact effects have been of an entirely different nature. Here large and small blocks of Ordovician sediments ranging up to 100 yards across, lying close to the roof of the batholith, have been strongly felspathized, giving rise to a granitoid rock as an end product. The petrology of these rocks will be dealt with at a later stage.

Along the north side of the granodiorite-Ordovician contact at the Black Hills, the greywackes and quartzites have been strongly brecciated. The appearance of these breccias led Stirling (1899) to conclude that they marked the site of a great thrust fault and that the narrow tongue of Ordovician rocks had been thrust into its present position from the north. Ferguson did not support this view but considered the breccias to be the result of purely local crushing. The present work supports Ferguson's view. Ironically enough, one side of this narrow tongue has been faulted, but it is the opposite side to the brecciated zone. On the brecciated side a sharp contact between granodiorite and hornfels occurs (section 7726).

Microscopic examination of these breccias (Nos. 7609, 7610) shows that the hornfels is traversed by innumerable minute fractures which break up the rock into small fragments. However, there has been little movement along these fractures—the fragments have remained essentially in place. It is clear, therefore, that this is not, as Stirling thought, a fault breccia, but would be better termed a crush breccia. Similar rocks have been found interbedded with the Snowy River Volcanics. Thin bands of sediments have been overlain by rhyodacite which has metamorphosed them somewhat, rendering them brittle and hard. Subsequently, the rhyodacites were folded. The resultant interformational stress on the incompetent sediments has given rise to crush breccias exactly the same as those which occur at the granodiorite hornfels contact at the Black Hills.

The breccias at the Black Hills were formed in the same way. Metamorphism of the sediments by granodiorite rendered them brittle. Subsequent regional stress has caused crushing at the contact without faulting, resulting in the formation of multitudinous small fractures, giving rise to a breccia. The granodiorite on the other side of the tongue has yielded by extensive shearing and hence breccias have not been developed. However, this aspect will be enlarged upon subsequently.

Weathering of these rocks has been controlled by the innumerable fractures, and hence each individual fragment is made to stand out in strong relief on a weathered surface, emphasizing the brecciated structure (hand specimens A6, A7, University of Melbourne Collection). It is noteworthy that brecciation of this type occurs only in metamorphosed sandstones and greywackes, and not in metamorphosed slates, shales and mudstones.

## SILURIAN

### *Granodiorite*

A large area of granodiorite occurs in the Deddick district, centred around the junction of the Deddick and Snowy Rivers, and extending eastwards up the Deddick Valley. Granodiorite also occurs in the north around Suggan Buggan, and in the far west along the Buchan River. It is probable that these outcrops are all connected and that granitic rocks underlie considerable areas of the Snowy River Volcanics in the district. The granodiorites form the southern part of a large batholith which extends northwards into New South Wales past Mt. Kosciusko and Cooma. In the Deddick region all the land which is utilized is underlain by granodiorite. When cleared it supports a moderate growth of pasture, and much of the Deddick valley is used for grazing. No farming or grazing is done in the area occupied by rhyodacite, or Ordovician sediments around Deddick. However, on the Wulgulmerang Plateau, rhyodacite gives rise to good grazing country, as does the basalt.

In the Deddick area, there are all gradations present between granites and granodiorites. However, rocks ranging in composition from adamellite to true granodiorite appear to predominate. An interesting feature is the common presence of large amounts of cordierite both fresh and pinitised.

In general, the rocks consist of quartz, andesine ($Ab_{60}An_{40}$), orthoclase, microperthite, cordierite, abundant biotite and occasional apatite. In slide No. 7615 andesine occurs commonly in idiomorphic tabular crystals, frequently zoned. Sericitisation of the cores is very common. Smaller amounts of orthoclase and microperthite occur in approximately equal amounts. They tend to occur interstitially to the biotite and andesine. Anhedral crystals of quartz are abundant. They are frequently fractured and carry considerable amounts of small inclusions arranged in linear fashion. Biotite is abundant in euhedral crystals and is pleochroic from light yellow to dark brown, almost black, indicating lepidomelane. Crystals of apatite are frequently included in the biotite, some of which has suffered a considerable amount of secondary alteration to chlorite, and to a lesser extent, iron ore. Small rounded zircons and an occasional small crystal of sphene occur as accessories. Cordierite occurs as a few large rounded crystals up to 3 mm. in diameter. Inclusions of prismatic sillimanite are common. The cordierite also contains rounded inclusions of quartz and biotite crystals, and occasionally of felspar. Apparently it has crystallized at a relatively late stage. It is usually fairly fresh, showing only a small degree of alteration to chlorite and pinite, however some of the crystals have been completely altered to chlorite.

In contrast to the above section No. 7614 contains a large amount of microperthite, making the rock a true granite. The microperthite occurs as large poikilitic plates enclosing all the other minerals of the rock. This specimen has been slightly altered, resulting in partial sericitisation of andesine and the development of muscovite, mainly from biotite. The alteration may be due to its proximity to the rhyodacite contact at Little River, only 300 yards away. Cordierite is of common occurrence in this rock, too. One crystal measures 6 mm. across. It is only partly pinitised, and its mutual relations with other minerals are similar to those described in section 7615.

Slides Nos. 7628 and 7630 are essentially similar to those described above. However, they tend more towards adamellites in composition.

The late stage differentiates of the granodiorite consist predominantly of aplites, which are quite common. Pegmatites are absent. The aplites occur mainly as dykes occupying tension cracks formed in the granodiorite during cooling. The dykes are frozen to the walls of the granodiorite and do not occupy fault planes. In two places, aplitic rocks occur in massive form—near the Little River contact, and about one mile along the spur leading north from the Sugarloaf. At the latter locality the aplites show all stages of gradation into masses and segregations of typical vein quartz. Hand specimens B 18, B 19.

The granodiorite has been intensely shattered by tectonic movements but has not developed any gneissic structures. Intense jointing and fracturing extend throughout the intrusion; it would be difficult in most places to obtain a 2 ft. cube of granodiorite without several fractures. Slickensides are extremely common, Usually they indicate horizontal movement. Offsetting of aplite dykes is also very common and illustrates well the relative movements of adjacent blocks. This intense shattering was probably caused by the tectonic movements which folded the Lower Devonian Rhyodacite in Epi Middle Devonian time. (See pages 68, 94.)

Previous to the shattering, fractures of a different kind were formed in the granodiorite. These are very persistent and some can be traced for as much as two miles along the strike, which lies at 150°. These fractures were subsequently occupied by lamprophyre dykes and mineral lodes. Smaller complementary fractures were formed simultaneously along an E-W strike. These will be discussed in greater detail at a later stage.

The granodiorite has intruded the Ordovician sediments but is older than the Snowy River Volcanics. In most places the granodiorite-Ordovician contacts do not present any unusual features. There is, however, one outstanding exception. A long narrow tongue of Ordovician rocks from 200 to 800 yards wide extends from near the junction of the Suggan Buggan River with the Snowy in a direction 150° for about 2½ miles. (See Fig. 2.) Continuing along the same strike, a large fracture extends from this tongue for another two miles until it disappears beneath the rhyodacite. The fracture is a broad mylonitised zone of granodiorite up to 100 ft. wide (Hand specimens K2, K3, K4, K5). It contains numerous brecciated inclusions of Ordovician sandstones. The north-east granodiorite-Ordovician contact was discussed previously; it has been crushed and brecciated, but it is nevertheless a normal intrusive contact. The south-west contact is a fault for some distance at least, since the fracture zone mentioned above is continuous with it.

At first sight, these relationships suggest that the elongated inlier of Ordovician rocks owes its existence to the fault just mentioned. However, it will be shown at a later stage that the granodiorite block south-west of the fault has moved *downwards* along the fault. This proves that the south-west boundary of the inlier was not created by faulting, and that this elongated inlier was, in fact, in existence before the faulting occurred. The fault has occurred along a normal granodiorite-Ordovician contact already in existence. This interpretation is proved by an examination of the metamorphic aureoles of the granodiorite. The metamorphism is strongest at *both* boundaries and becomes less pronounced towards the centre of the inlier. Consequently the south-west boundary must originally have been of normal intrusive origin.

The question is now raised regarding the origin and significance of this long narrow tongue of Ordovician rocks together with the presence of Ordovician fragments in the mylonite zone farther along the same strike. The feature is clearly of primary origin and is connected with the mechanism of intrusion of the granodiorite. The intrusion process has evidently been controlled by major fractures.

The presence of numerous fragments of Ordovician sediments in the mylonite zone proves that large blocks of Ordovician sediments must either lie enclosed below in the granodiorite along the fault line, or else they have existed previously and have been removed by erosion.

In Victoria, similar "screens" of sedimentary blocks occur at the junction of two separate intrusions at Powelltown and Everton (E. S. Hills, personal communication), and in the Strathbogie Ranges (D. White, personal communication). It is this fact which suggests that the screen described above may have a similar origin, and may lie along the boundary of two distinct phases of the one intrusion. Petrologically there does not appear to be any difference in the two phases; however, it is noticeable that the granodiorite north-east of the contact contains far more xenoliths.

In most places the granodiorite has formed an aureole of low grade hornfels in the sediments. However, in one area near the roof of the batholith metamorphism of a different kind has occurred. Granitization of large xenoliths of Ordovician sandstone has taken place, giving rise to an end product of granitoid appearance. The xenoliths thus granitized range in size up to one hundred yards across and occur about one mile along the spur leading north from the Sugarloaf.

The transition between slightly granitized bedded sediments and a completely granitoid rock can be followed without difficulty in the hand specimen. In hand specimen B12 the bedding of the original sandstone has been retained, only the bedding now consists of alternate bands rich in biotite, quartz-felspar, and pure felspar, about 1 to 3 millimetres wide. In B11 also the original bedding has been completely retained. In B10, B9 and B13, traces of the original sedimentary structure have been obscured and a granitoid rock consisting of felspar biotite and quartz results.

The changes may be followed under the microscope but subsequent alteration obscures some of the features. Most of the felspars have either been kaolinised, or altered to aggregates of micaceous minerals—muscovite, green biotite and chlorite. The original brown biotite has also been extensively chloritised. The widespread alteration is probably due to contact metamorphism by rhyodacites of the Snowy River Volcanics which would originally have overlain the granitised sediments at no great height. They have now been removed by erosion.

Slide 7624 shows the process of granitization of a medium grained impure sandstone in the earlier stages. Biotite is abundant and possesses a preferred orientation parallel to the bedding (which, however, is not as well displayed in the slide as in the hand specimen). The biotite is invariably partly chloritised and bleached by subsequent alteration. Innumerable kaolinised felspar crystals are present. Mostly they are about the same size as the quartz grains and appear to be developing interstitially to the latter. They appear to have replaced completely the cementing medium which originally bound the grains together, rather than the quartz grains. Biotite on the other hand has replaced both cement and quartz grains in its efforts to form euhedral crystals. On one edge of the slide, a veinlet about 1 millimetre wide of coarse orthoclase crystals has developed parallel to the bedding.

No. 7623 shows the process further advanced in what was originally a fine-grained greywacke. The interstitial felspar has commenced to replace the quartz grains more extensively than in 7624. A vein of orthoclase parallel to the bedding likewise occurs in this specimen. No. 7626 shows a coarse-grained sandstone being replaced by felspars which are either kaolinised or represented by pseudomorphs of micaceous minerals. The felspars, both orthoclase and plagioclase, are in the process of replacing quartz along intergranular boundaries and are tending to attain a euhedral shape at the expense of the quartz grains. In one corner a felspar porphyroblast has developed consisting of an aggregate of distinct crystals of orthoclase and plagioclase. No. 7622 shows the same process. There has been, also, some recrystallisation and grain growth of quartz in the specimen. No. 7624 shows the selective nature of the replacement of a bedded sediment. Pure quartzite layers have undergone little change, but adjacent layers, originally richer perhaps in argillaceous material, have been extensively replaced.

No. 7627 shows an advanced stage of granitization with euhedral-subhedral porphyroblasts of felspar up to 3 millimetres across developed right throughout a sandstone. As usual, the felspars have either been kaolinised or completely replaced by micaceous aggregates.

The introduced felspar is usually orthoclase, although albite is common in places.

One of the earliest stages in the process of granitization appears to be the development of biotite, probably largely from material contained in the original impure sandstone. It is noticeable that in the more quartzitic bands biotite is not common. The early growth of biotite is seen on slide 7624 where biotite is extensively developed in euhedral crystals whereas the felspars only occur at grain interstices in small anhedral crystals. At a later stage, felspathization becomes more marked, proceeding along the grain boundaries, replacing both quartz grains and the cementing medium. The felspars eventually attain euhedral shape (Nos. 7622, 7626) and finally porphyroblasts develop (No. 7627). At all stages of granitization, thin bands of felspar may develop in lit-par-lit fashion, parallel to the bedding. These bands of felspar could be due to either

(1) the chemical nature of an original layer of the sedimentary rock which may promote preferential reaction with the felspathizing medium;

(2) the higher permeability of some original layers in the sediment which gives easier access to the granitizing medium.

It is not possible to distinguish the more important factor.

The fact that felspathization commences in the interstices between grains, and replacement of quartz grains occurs from the boundaries inwards, seems to indicate that the felspathizing medium was a liquid which penetrated the intergranular boundaries by capillary processes.

The granitization is therefore apparently due to the action of hot aqueous solutions emanating from the granodiorite magma. The fact that the only place where appreciable granitization occurred was near the roof of the batholith is of some significance. At lower levels, sediments have been changed into low to medium grade hornfelses by the granodiorite. These two different types of alteration are probably due to variation in the water content of the original magma. In the region where little water is present, in the magma, hornfels is the typical contact rock but when the magma contains abundant water in solution felspathization of sediments may be the dominant tendency. This fact is in harmony with the views of Emmons (1933) who has pointed out that water and other volatiles tend to concentrate near the roof of intrusions.

XENOLITHS. Xenoliths in the granodiorite are sometimes abundant, but their distribution is irregular. Most of them are dark and rich in ferromagnesian minerals. Closer inspection reveals that they are fragments of schists and gneisses (Hand specimens B26, B29, B30, B31, B32). Under the microscope they are seen to consist mainly of cordierite-biotite-sillimanite schists. Cordierite, either fresh or altered to pinite and chlorite, is by far the most abundant mineral present, usually making up the bulk of the rock, e.g. slides 7732, 7733. When fresh it often displays polysynthetic twinning. In section 7735 the chlorite derived from cordierite contains large numbers of elongate inclusions of magnetite. The texture is not unlike the characteristic exsolution textures observed in some ore minerals. In this case, however, it is probable that the magnetite is derived from excess iron present in the rock which could not be incorporated in the cordierite crystals during growth. In places, biotite also has partially broken down to give magnetite. Sillimanite is characteristically associated with cordierite, usually included as fine prisms or fibrous aggregates. In slide 7732 it has developed into much larger prismatic crystals.

The presence of such large numbers of xenoliths of schists and gneisses in the granodiorite is interesting, in view of the fact that the surrounding Ordovician rocks are unaltered sediments, apart from some low to medium grade hornfels at the granodiorite margins.

The schists and gneisses resemble those occurring in the Eastern Victorian metamorphic complex centering around Omeo. The nearest locality where rocks of this type occur is near Bindi, about 30 miles distant.

Two explanations may be advanced regarding the origin of the xenoliths. Convection currents in the magma of the Corryong Batholith may have transported the xenoliths for considerable horizontal distances, thus accounting for their distribution. Alternatively, it may be that the normal unmetamorphosed Ordovician sediments at Deddick pass downwards into a zone of schists and gneisses. Such a gradation has been observed elsewhere in Eastern Victoria. The deep lying zone of gneisses and schists would be caused by an earlier phase of igneous activity. This zone may have been invaded later by normal granodioritic magma, as has happened at Omeo. The later granodioritic magma is thereby able to incorporate xenoliths of schists and gneisses which may be carried up higher in the crust to a zone which had not previously been metamorphosed.

Large garnets occur rarely in the granodiorite at Deddick. They range in size up to half an inch across, and are invariably rimmed by cordierite and biotite. The cordierite is usually altered to pinite and chlorite. These garnets are only found in granodiorite where it is rich in xenoliths. Apparently the garnet can crystallize only from a contaminated magma.

The R.I. of the garnet is 1·80, indicating that it is probably a variety of almandine, and the colour is always red. Small euhedral crystals of magnetite are frequently included (Slide 7737) (Plate III, fig. 4). Surrounding the core of garnet is a reaction rim of cordierite, usually pinitised or chloritised, and surrounding the cordierite is a rim of biotite. These are well displayed in Plate III, fig. 4. The cordierite often contains extremely large numbers of small biotite crystals as inclusions (Slide 7737). Unlike the outer rim of biotite which has developed due to reaction between the cordierite and the magma, these appear to have been formed simultaneously with the cordierite, due to reaction of the garnet with the magma.

The simultaneous formation of biotite with cordierite is probably caused by the inability of cordierite which has developed from the iron rich almandine to hold as much iron as the almandine (Folinsbee, 1941). Accordingly, the presence of excess iron has caused the formation of some biotite.

The subsequent reaction of the cordierite with the magma may likewise be due to instability caused by the cordierite possessing a much higher Mg/Fe ratio than was present in the magma. Cordierite which has crystallized directly from the magma shows no such instability.

Age of Granodiorite. The granodiorite intrudes Upper Ordovician sediments and underlies unconformably the Snowy River Volcanics of Lower Devonian age. In view of the great thickness of the Snowy River Volcanics, and the frequent intercalations of sedimentary rocks, it seems that the formation of the volcanics must have occupied at least a substantial part of the Lower Devonian epoch. Furthermore, when the considerable length of time necessary to expose the batholith by erosion prior to extrusion of the volcanics is also considered, it seems probable that the granitic rocks must be of Silurian age.

## Lower Devonian

The Snowy River Volcanics outcrop over a considerable portion of the area studied. They consist predominantly of rhyodacites with lesser amounts of intercalated latites, sediments and pyroclastics. They rest unconformably upon a basement of granodiorite and Ordovician rocks and have been folded along north-south axes into two synclines separated by an anticlinal structure.

These rocks were first studied by Howitt (1876, 1878) who called them the "Snowy River Porphyries"; this name was changed to "Snowy River Series" by Gaskin (1943). The term "series" however applies to the rocks laid down during one epoch, and in view of the possibility that some of the flows of rhyodacite may be of Upper Silurian or Middle Devonian age, the name "volcanics" has been substituted.

Howitt (1876) made a traverse through part of the Little River Gorge and came to the conclusion that the Snowy River Volcanics consisted of about equal thicknesses of massive quartz porphyries, and felsites, forming a basal group, and fragmental rocks, mainly tuffs and agglomerates, which formed an overlying group. He estimated the minimum thickness of the Snowy River Volcanics to be about 2,000 ft. He also suggested that the contact of the rhyodacites with the granodiorite at Little River was a major fault extending up to Suggan Buggan.

Detailed mapping by the author does not support the existence of a fault, but Howitt's other views are partially substantiated. The thickness of the flows is much greater than that suggested by Howitt, reaching 10,000 ft., of which the bottom 8,000 ft. consists mainly of porphyritic rhyodacites.

The rhyodacites have been extruded in a large number of separate flows, of which three are by far the most important. Petrologically the rhyodacites differ in only minor respects and the recognition of the different flows in the field is often extremely difficult. If the rocks are fresh it is possible to distinguish one flow from another simply upon the basis of texture in the hand specimen. Rarely a microscopic section may be necessary. However, extensive secondary alteration is universal throughout these rocks, and if this has gone too far the only way to distinguish definitely is by microscopical examination. Apart from texture, other important criteria which aid in distinguishing flows are colour, nature of weathering, and characteristic xenoliths. The criteria will be dealt with in detail when the petrology of these rocks is described.

At this stage, a discussion of nomenclature may be appropriate. The acidic volcanic flows of the Deddick district have all been called "rhyodacites". This term was applied by Gaskin (1940) and Cochrane and Samson (1947) in their descriptions of similar rocks. The latter authors apparently used this name for two reasons. Firstly two chemical analyses of typical rocks by Teale (1920) showed that they were best described as rhyodacites. Secondly orthoclase phenocrysts were believed to be present as well as plagioclase phenocrysts, although they were much less abundant.

As a result of his work on the Deddick rocks, and a re-examination of Cochrane and Samson's slides, the author now believes that it is very doubtful whether orthoclase phenocrysts are present. It seems quite likely that the "orthoclase" is in reality untwinned albite. If this is so, however, it will not affect the classification proposed, since this finds sufficient justification in the chemical analyses. The high potash content must be contained mainly in the groundmass.

In the Deddick rocks, all stages of albitization of andesine phenocrysts may be observed in some rocks, and it therefore seems reasonable to assume that when an altered looking rock containing only albite phenocrysts is found, these phenocrysts were originally of andesine. Accordingly the name "rhyodacite" has been retained for rocks of this type having regard for their probable original composition, although their present chemical composition might be more akin to that of soda rhyolites.

The Snowy River Volcanics at Deddick may be subdivided as shown in Fig. 3. This has not been drawn to scale.

### *Deddick Rhyodacites*

The Deddick Rhyodacites constitute the basal members of the Snowy River Volcanics. They are widespread in the Deddick-Wulgulmerang area and attain their maximum thickness of about 3,100 ft. in the Little River district. The flows thin out in all directions outwards from Little River. To the east, in the Deddick area, the thicknesses range from about 300-1,000 ft., whilst northwards towards Suggan Buggan the total thickness is only 200 ft. At Campbell's Nob, which is four miles south of the area under consideration, the thickness is about 200 ft.

The Deddick Rhyodacites are probably continuous at the base of the Snowy River Volcanics in nearly all parts of the area. There are only two areas where they do not occur at the contact of the Volcanics and the basement rocks. Both occurrences are due to faulting. At Seldom Seen on the contact along the Buchan River divide, the absence of Deddick Rhyodacite is clearly due to faulting. Fault breccias of Ordovician rocks lie against the Black Mountain Rhyodacite. The fault does not continue as far south as Gelantipy where Deddick rhyodacite is again found to be next to the granodiorite. The other occurrence is at Wheelers Creek where Gelantipy Rhyodacite rests against Ordovician rocks. This is likewise due to faulting.

The Deddick Rhyodacites are made up of a group of several separate flows interbedded with which are occasional thin sedimentary beds, a latite flow, and two flows of "minor" rhyodacites. Petrologically the Deddick Rhyodacites may be divided into two different types. Gradations between these two types occur near the top of the group.

The most striking is a strongly porphyritic rock, light coloured when fresh (Hand specimens D7, D10) which may turn to reds, browns, purple or dark green when weathered. (Hand specimens D6, D9, D12.) D9 is a typical example of porphyritic Deddick Rhyodacite. The hand specimen is a brown porphyritic rock containing phenocrysts of quartz and felspar up to 5 mm. across, and occasional smaller chloritised biotite phenocrysts, set in a fine-grained groundmass. Felspar phenocrysts are in excess of quartz, but quartz phenocrysts are frequently larger than the felspars.

Under the microscope (slide 7644) the felspars are seen to consist of albite $Ab_{93}An_7$. The felspar is euhedral to subhedral in form. Some albite phenocrysts are seen to consist of clots of several crystals twinned in a very complex manner. Alteration is universal, usually in varying degrees to sericite and kaolinite. A few anhedral quartz phenocrysts are present, reaching 4 mm. in size. These are invariably cracked and often show traces of resorbtion by the groundmass. They usually contain numerous embayments and inclusions of groundmass material, sometimes glassy, sometimes crystalline.

Biotite is present as a few phenocrysts up to 2 mm. across. It is invariably altered and bleached, mainly to chlorite, epidote, sphene and leucoxene. Associated

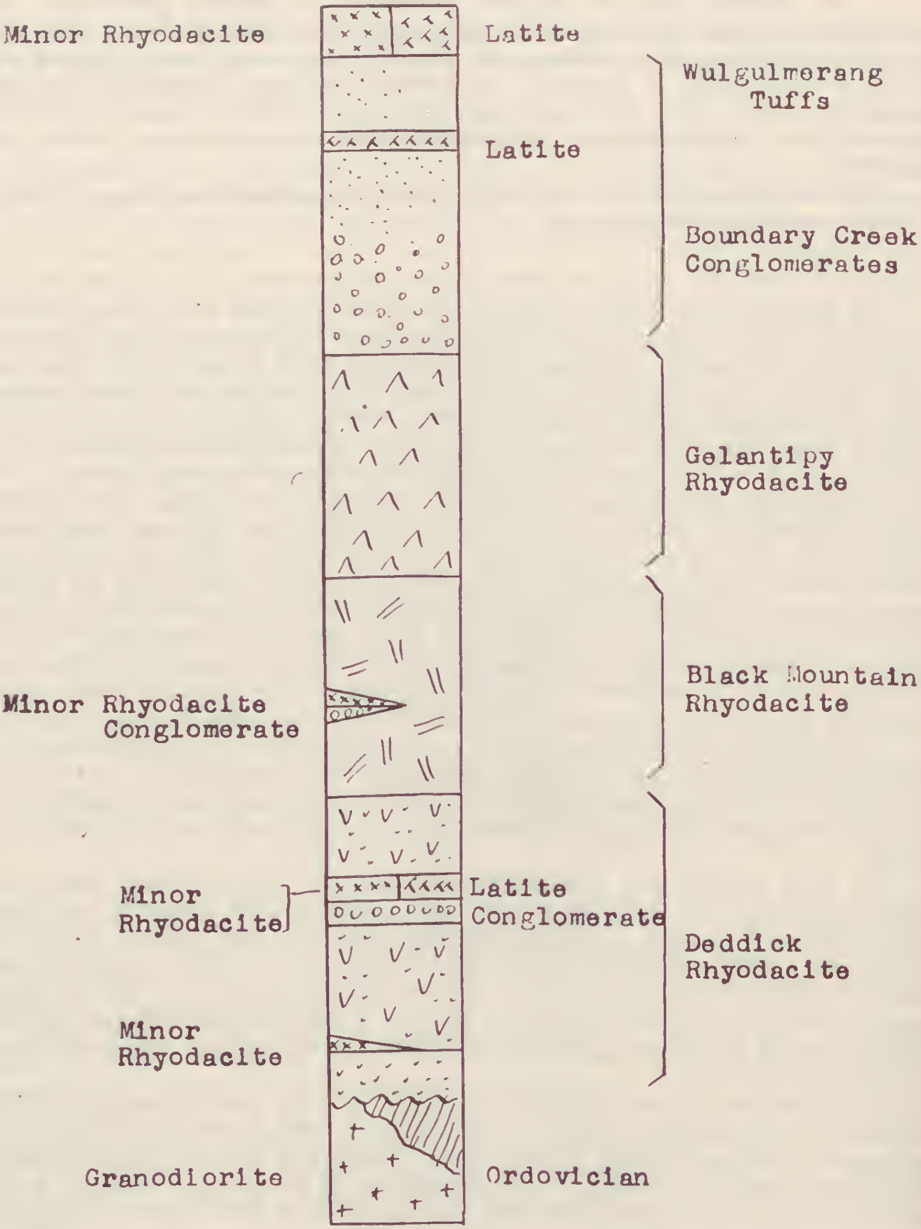

Minor Rhyodacite
Latite
Wulgulmerang Tuffs
Latite
Boundary Creek Conglomerates
Gelantipy Rhyodacite
Black Mountain Rhyodacite
Minor Rhyodacite Conglomerate
Minor Rhyodacite
Latite
Conglomerate
Deddick Rhyodacite
Minor Rhyodacite
Granodiorite
Ordovician

Fig. 3

with the biotite there are a few zircons and an occasional large apatite prism. Alteration to secondary muscovite along cleavage planes is also quite common. The groundmass consists of a microcrystalline aggregate of alkali felspar and quartz. Finely divided chloritic material and hydrated iron oxides derived from magnetite particles are responsible for the greenish brown colour.

No. 7636, coming from about half a mile east of the Sugarloaf, is fairly similar to No. 7644. An interesting feature of the rock is the presence of coronas of alkali felspar around quartz phenocrysts. They appear to represent orientated overgrowths, and extinguish uniformly.

No. 7635 is a slightly sheared rhyodacite taken at the granodiorite contact near the Sugarloaf. Its quartz phenocrysts often show evidence of resorbtion. In slide No. 7638 the groundmass is very finely crystalline and it probably represents a devitrified glass. No. 7632 from Little River furnishes another example of alkali felspar coronas in optical continuity with quartz crystals. It also contains a small basic inclusion.

The second type of Deddick Rhyodacite is exemplified by hand specimen D16. It is a hard, light-coloured rock containing occasional small phenocrysts of quartz and felspar, generally smaller than 2 mm. in diameter. It weathers to give a typical bright yellow surface, and when strongly weathered it is difficult to distinguish from a tuff.

Under the microscope the felspars (No. 7633A) are seen to consist dominantly of euhedral crystals of albite $Ab_{94}An_6$. A few crystals of orthoclase (?) are also present. Biotite has been completely replaced by epidote and chlorite. Small granules of the former are widely distributed throughout the groundmass. Quartz is common, mostly as very small crystals, but one large phenocryst occurs. A vesicle has been lined with crystalline quartz. The groundmass is a very fine-grained devitrified glass. Some samples (e.g. Nos. 7640, 7643) of this rock display a very well-developed flow structure both macroscopically and microscopically. No. 7640 contains abundant small quartz phenocrysts, which are more numerous and larger than the felspars. It has been subjected to shearing and small veinlets of quartz now occupy the fractures.

The fine-grained Deddick Rhyodacite forms the earliest flow. It outcrops along most of the north-south striking contact at Little River. However, this early flow does not extend over to the east side of the Snowy River. Overlying this is a thick flow of porphyritic Deddick Rhyodacite. This flow is widespread on both sides of the river and forms the basal flow over most of the Deddick district. Overlying this is a very extensive flow of the fine-grained rhyodacite. The two flows of fine-grained and porphyritic rhyodacite are all that occur on the east side of the river. However, on the west side, around Little River, a considerable thickness of interbedded fine-grained and porphyritic Deddick Rhyodacite together with transitional varieties, overlies the extensive flow of fine-grained rhyodacite. As mentioned before the total thickness of Deddick Rhyodacite in the Little River area reaches 3,300 ft.

Intercalated with the Deddick Rhyodacite are relatively thin beds of sediments and flows of "minor" rhyodacite and latite, which will be described in detail subsequently.

The Deddick Rhyodacites are extremely hard rocks which consequently find topographic expression as high rugged ridges, whereas the rocks on either side—granodiorite and Black Mountain Rhyodacite—have been eroded down to a much lower level (Plate II).

*Black Mountain Rhyodacite*

Overlying the Deddick Rhyodacite is a second great flow which is remarkably homogeneous in texture and composition. This has been termed the Black Mountain Rhyodacite after an area in which it is well developed. It is both the most widespread and consistently thickest member of the Snowy River Volcanics. Its thickness in the Little River section is 2,500 ft. On the east side of the Snowy River it stretches from Deddick across to Accommodation Creek, in the far east, and southwards to Campbell's Nob. North of Black Mountain as far as Limestone Creek and the Cobberas, the plateau consists of Black Mountain Rhyodacite alone. It then extends continuously southwards to Buchan and Nowa Nowa in two broad parallel belts, forming limbs of a synclinal structure. The Black Mountain Rhyodacite appears to have been erupted in a relatively small number of individual flows. In this district only one discontinuity has been found—a thin band of conglomerate near the base of the flow in the Deddick district.

The hand specimen shows a strongly porphyritic dark rock closely packed with phenocrysts up to 5 mm. across, of quartz and felspar set in a dark glassy groundmass. Around Deddick, the groundmass is usually black although weathering gives rise to a red colour. In the west, however, along the Buchan River divide, the dominant colour is red. There are all gradations between the red and black rhyodacites. Under the microscope the colour is seen to be due to the state of oxidation of the iron ore in the groundmass. In the black rocks (e.g. E2, 7646) the groundmass contains a large amount of very fine dispersed magnetite dust, whereas in the red variety (e.g. E1, 7645) the groundmass contains fine hematite dust. It is clear therefore that the different colours are of little petrogenetic significance.

No. 7645 is a typical example of the black variety. Basically it differs little from the porphyritic Deddick Rhyodacite, and comment will be confined mainly to the differences. The phenocrysts are very numerous and closely spaced, and are set in a very fine cryptocrystalline groundmass which is apparently a devitrified glass. Both albite and andesine are present as phenocrysts, with all the stages of replacement of andesine by albite exhibited. The andesine present is of a composition $Ab_{54}An_{46}$ and has been extensively altered to epidote sericite and sometimes calcite, besides albite. The original ferromagnesian minerals have been completely altered to aggregates of chlorite, magnetite, calcite, sphene, leucoxene and epidote. Most of the pseudomorphs appear to be after biotite but some probably follow hornblende. The pseudomorphs are numerous and range in size up to 3 mm. across. Octohedra of magnetite up to ½ mm. across are common as accessory minerals. Zircon and apatite occur sparingly in euhedral crystals.

Numerous other slides show much the same features. In some, flow structures are well developed in the groundmass. In sections 7646, 7648, 7650, the replacement of andesine by anastomosing veinlets of albite is well displayed. The andesine tends to be slightly more sodic, ranging between $Ab_{60}An_{40}$ and $Ab_{55}An_{45}$.

A second variety of Black Mountain Rhyodacite occurs along the Buchan River divide and in places on the plateau behind Black Mountain, e.g. Mount Wombargo. This variety differs from the normal type in that it is somewhat coarser in texture and possesses a microcrystalline groundmass. The colour of the variety is usually red. Apart from these slight differences, it is similar to the common Black Mountain Rhyodacite (e.g. E13, E14, E15; 7657, 7658, 7659).

In many areas the Black Mountain Rhyodacite contains abundant small xenoliths of sedimentary origin derived from Ordovician rocks (No. 7645) and also of Deddick Rhyodacite (No. 7649).

In the Wulgulmerang Plateau around Black Mountain this flow outcrops over a large area, and has developed quite a good soil. In the Little River Gorge, the Black Mountain Rhyodacite is less resistant to weathering than neighbouring Deddick and Gelantipy Rhyodacites, and a stream valley lies along its outcrop. (Plate II.) However, at the edges of the Wulgulmerang plateau the Black Mountain Rhyodacite forms resistant strike ridges. The long range stretching from Mt. Wombargo southward along the Buchan divide past Mt. Statham and Mt. Murrindal is composed of this flow. Howitt (1876) suggested that this ridge represented the outcrops of a line of median volcanoes which gave rise to the Snowy River Volcanics. This view was based partly upon the fact that these rocks are sometimes a little coarser than the more widespread Black Mountain rhyodacite—a fact which has already been commented upon. However, this fact is of no genetic significance and can only be regarded as a minor textural variation. The field and microscopic evidence shows clearly that the "line of median volcanoes" is in reality the outcrop of the bedded Black Mountain rhyodacite on the western limb of the syncline. (Figs. 1 and 4.)

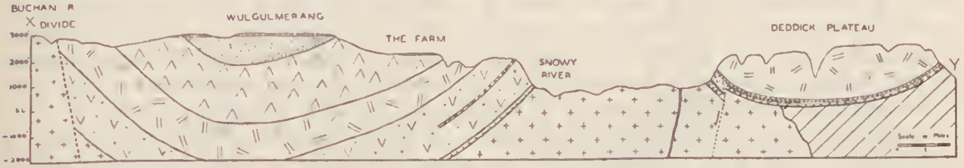


FIG. 4

*Gelantipy Rhyodacite*

The Gelantipy Rhyodacite occurs only on the west side of the Snowy River, where it overlies the Black Mountain Rhyodacites. In the Little River Gorge it is about 2,700 ft. thick. It maintains and possibly increases this thickness towards the south. However, it is not found in the northern part of the area, being suddenly cut off by a major fault, trending east-west, just south of Black Mountain. It is found along the fault, but is only a few hundred feet thick. The significance of this feature will be considered later.

The Gelantipy Rhyodacite outcrops in two parallel bands striking north-south; one near the Buchan Divide and one in the Little River-Farm area. These two outcrops dip inwards, and form a synclinal structure. Towards the south the outcrops converge at Gelantipy, thus forming a basin-shaped structure open at the northern end. It then extends continuously southwards for a considerable distance. Reconnaissance mapping indicates that it dies out just north of Murrindal.

Thin sections of the Gelantipy Rhyodacite reveal close affinities to the Black Mountain Rhyodacite. A notable feature, however, is the almost complete absence of ferromagnesian phenocrysts of pseudomorphs in the later flow. (Slides 7660, 7661.) An occasional small crystal of magnetite is all that occurs. The quartz phenocrysts are about as numerous as the felspars and in contrast to the Black Mountain Rhyodacite display a strong tendency to form idiomorphic doubly terminated hexagonal pyramids and prisms. Furthermore, these crystals are not embayed or cracked nearly as much as those in that flow. The felspars consist of albite $Ab_{98}An_2$ and a small amount of residual andesine. Xenoliths are very common and have often been partially melted and drawn out in the direction of flow. Xenoliths include sedimentary rocks (from the Ordovician basement) tuffs, Deddick Rhyodacites, and intermediate rocks.

When fresh the Gelantipy Rhyodacite from different localities is fairly homogeneous in texture and composition. However, because of secondary alteration, the hand specimens display a bewildering variety of appearances, and recognition of this rock in the field is often a difficult matter. Relatively fresh specimens are difficult to procure—the freshest seen by the author occur in the bed of the Little River Gorge and in some deep roadside cuttings directly overlooking the Little River Gorge. Even in these (slide 7660) the felspars are somewhat sericitised. When fresh the rock is seen to be of ordinary porphyritic texture with quartz and felspar phenocrysts set in a grey glassy groundmass. The main difference from the Black Mountain Rhyodacite is the smaller size of phenocrysts and the more open packing. No attempt will be made to describe the numerous varieties of weathered Gelantipy Rhyodacite, but a representative selection has been placed in the Melbourne University rock collection. Microscopically the principal effect of weathering is seen to be complete seriticisation of felspars (slides 7662, 7663). It is strange that the Gelantipy Rhyodacite which is so similar to the Black Mountain Rhyodacite exhibits such a different behaviour during weathering. This is possibly due to the inherent properties of the groundmass which in each case is a devitrified glass. Slight differences in chemical composition in glasses are frequently known to cause considerable difference in their physical and chemical properties. It may be that the fact that the glass of the Gelantipy Rhyodacite is apparently poorer in iron and magnesium than that of the Black Mountain Rhyodacite is responsible for the different behaviour.

Economically the Gelantipy Rhyodacite is of no importance. Nowhere has it developed a decent soil; the outcrops have given rise either to rocky ground supporting inferior timber, or in more deeply dissected areas, to gorges with precipitous sides, as at Boundary Creek and Little River.

The Gelantipy Rhyodacite has been erupted in several flows which are often separated by thin beds of fragmental rocks—mainly tuffs and conglomerates.

These three rhyodacites constitute the major flows in the Snowy River Volcanics, and since they are chemically and texturally so similar, it has been thought advisable to set out the criteria for differentiation in tabular fashion. (Table 1.)

### *Intercalated Minor Rhyodacites*

Associated with the three major flows of rhyodacite are several much smaller flows. They are rarely more than a couple of hundred feet thick, and are of purely local significance. Petrologically they possess certain features in common—they are all of porphyritic texture, but the phenocrysts are generally less than 1 mm. across although they may be closely spaced. A second similarity is that on the whole they are richer in ferromagnesian minerals than the three earlier flows. Indeed, a few of these rocks would almost fall into the quartz latite class. They appear to represent transitional varieties between the major flows of rhyodacite which are low in ferromagnesians, and the latites. A convenient name, to cover all of these small flows, which occur at different horizons is "Intercalated Minor Rhyodacites".

Rocks of this type occur at four separate horizons in the area mapped. On the divide between Old Joe's Creek and Running Creek, a flow about 30 ft. thick occurs below the porphyritic Deddick Rhyodacite. It appears to be occupying a depression in the Ordovician bedrock, and dies out rapidly towards the west. The flow is sheared and has suffered much secondary alteration. It is a fairly quartz rich rhyodacite with a large amount of magnetite distributed throughout. (Section 7664.) A second flow occurs in the Deddick area directly below the fine-grained Deddick rhyodacite and overlying a bed of conglomerate and sandstone. The flow is in places a couple of hundred feet thick and outcrops continuously for a mile and a half in

Table 1

*Criteria for differentiation of Deddick, Black Mountain and Gelantipy Rhyodacites*

MACROSCOPIC

| | Colour | Size of Phenocryst | Fracture | Weathering | Xenoliths |
|---|---|---|---|---|---|
| Deddick Rhyodacite | Usually white, yellow, etc.<br>Also red, brown, grey. | Large, up to 5 mm. across. | Moderately smooth fracture surface. | Texture easily distinguishable. | Rare. |
| Black Mountain Rhyodacite | Varies from black - red. | Large, up to 5 m.m. across | Moderately smooth fracture surface. | Texture easily distinguishable. | Common in some areas. |
| Gelantipy Rhyodacite | Grey, yellow, purple, brown, etc. | Smaller than 3 m.m. | Irregular and jagged surfaces. | Original texture largely obscured.<br>Often resemble tuffs. | Common in some areas. |

MICROSCOPIC

| | Ferromagnesians | Plagioclase | Quartz | Groundmass | Phenocryst Density |
|---|---|---|---|---|---|
| Deddick Rhyodacite | Biotite predominant.<br>Usually recognizable. | Albite | Large crystals<br>Anhedral-Subhedral.<br>Fractured and embayed. | Microcrystalline. | Variable |
| Black Mountain Rhyodacite | Completely altered to chlorite and epidote pseudomorphs. | Andesine being replaced by albite. | Large crystals<br>Anhedral-Subhedral.<br>Fractured and embayed. | Cryptocrystalline sometimes microcrystalline. | Phenocrysts very closely packed. |
| Gelantipy Rhyodacite | Very rare. | Albite with a little residual andesine. | Smaller crystals.<br>Less fractured and embayed. Idiomorphic. | Cryptocrystalline.<br>Strong flow structure. | More open packing. |

the range lying north of the Sugarloaf. A third flow occurs near the base of the Black Mountain Rhyodacite along the divide between Old Joe's Creek and Running Creek. It overlies a conglomerate. Both lense out rapidly along the strike. It appears that this is a fossil deep lead, the conglomerate representing gravels in an old river bed down which the Minor Rhyodacite flowed. This was subsequently covered by Black Mountain Rhyodacite. This is also the only known location in the area where foreign rocks are interbedded with Black Mountain Rhyodacite. The fourth flow of Minor Rhyodacite occurs in Wulgulmerang, where the Deddick road crosses Little River. It is about 200 ft. thick, and outcrops over 100 acres, lying right near the top of the sequence.

Microscopically the Minor Rhyodacites are ordinary porphyritic rocks containing phenocrysts of quartz, albite, andesine and sometimes biotite, set in a groundmass which is usually cryptocrystalline, but sometimes microcrystalline. The albite is $Ab_{94}An_6$ whereas the andesine remnants have a composition $Ab_{54}An_{46}$. The albite is seen to have replaced andesine. Quartz phenocrysts are usually present in smaller amounts than felspars and in some slides (Nos. 7667, 7668) they are comparatively deficient. The ferromagnesians are usually represented by pseudomorphs of chlorite and epidote after biotite and hornblende. In slide 7667, however, green biotite is present and is only moderately altered. In the latter slide nests of epidote, probably pseudomorphic after amphibole, are found. Most of these rocks possess a cryptocrystalline groundmass similar to that of the Black Mountain Rhyodacite (Nos. 7668, 7671). In the latter slide, flow structures are beautifully developed.

In some specimens (slides 7673, 7674) xenoliths are quite common. There are several small inclusions of a fine-grained basic rock. The ferromagnesians have been altered to hematite and magnetite. Xenoliths of mudstone and sandstone also occur.

A characteristic feature of the Minor Rhyodacite near the Little River bridge is the presence of numerous inclusions of chlorite. (G16, 7677.) These occur right throughout the flow. Similar inclusions are found in parts of the second flow of Minor Rhyodacite near the Sugarloaf. (Nos. 7672, 7675.) These inclusions tend to be tabular in shape and are usually lensed out in the direction of flow. They range in size up to a centimetre long. They are far too large to be pseudomorphs after biotite; in any case, their irregular shape precludes this. Closer examination indicates that these are small xenoliths of rhyodacite, which have been incorporated in the magma, and later chloritised. (Slide 7675.) Their irregular lens-like shape is probably due to partial melting and being drawn out in the direction of flow. In slide 7675 and to a lesser extent in No. 7672 the process of chloritisation of rhyodacite can be clearly recognized. The groundmass of the xenoliths is strongly affected, phenocrysts being relatively resistant. The process may be seen in an early stage in the Black Mountain Rhyodacites, particularly along the Suggan Buggan road. Large rhyodacite xenoliths have almost invariably been impregnated by chlorite and all have a green appearance. (Slide 7649.) In this latter slide it is noticeable that the only one of the many xenoliths present which is suffering chloritisation is one of Deddick Rhyodacite. In 7675, however, there are several places where the development of chlorite aggregates seems to be independent of xenoliths. These, however, are only small and probably represent the remains of original biotite crystals.

The origin of this widespread chloritisation is connected with the general phenomena of secondary alteration which is so ubiquitous in the Snowy River Volcanics. This subject has been discussed by Cochrane and Samson (1947) and apart from observing that the types of secondary alteration which they found so common in the Nowa Nowa district are likewise common throughout the Deddick area, the author has no new data to contribute. Cochrane and Samson maintained that alteration of the chloritic type has been due to "active solutions which were probably formed by groundwaters dissolving out certain elements from the minerals of the volcanic rocks and re-depositing them elsewhere to form new minerals (chlorite, etc.), the channels being provided by the various major and minor fractures produced during the era of compression shear and warping which gave rise to the porphyroids". The author does not believe that this hypothesis explains the fact that complete chloritisation of all ferromagnesians in the Black Mountain Rhyodacite occurs to the same extent in regions which have suffered intense stress and shearing (Little River Gorge) as in places where very little stress has occurred, and no channelways have been opened up causing intimate penetration by ground waters (centre of Deddick Plateau). Accordingly he is inclined to attribute the alteration to the action of late magmatic solutions. It seems likely that the parent magma of the Snowy River volcanics had a fairly high content of water, and that this has been responsible for the alteration when concentrated at the late stages of crystallization.

Cochrane and Samson attribute the development of secondary albite in the Nowa Nowa rocks to the action of late stage soda rich solutions of magmatic origin. The Deddick rocks have suffered an even more intensive albitization than those at Nowa Nowa. In the Deddick Rhyodacite, complete replacement of andesine has occurred whilst considerable replacement has occurred in all other flows. For reasons similar to those suggested above, when considering chloritization the author would agree with Samson and Cochrane that the albitization must have been due to the action of late stage magmatic soda rich solutions.

### *Latites and Quartz Latites*

Cochrane and Samson described an andesitic suite from Nowa Nowa. In view of the analysis of a typical member of this suite by one of those authors showing $K_2O = 3{\cdot}98\%$; $Na_2O$ 2·39%; GaO 4·74%, it would be preferable to call these rocks latites and quartz latites. The high potash content apparently resides in the groundmass. Rocks similar to these occur in the Wulgulmerang district. However, they display a more advanced stage of secondary albitization than the Nowa Nowa rocks, the original andesine having been completely replaced by albite. Nevertheless, it has been thought preferable to continue to call them latites and quartz latites.

In the Wulgulmerang area there are three flows of latite present. The bottom flow occurs on the west side of the Snowy River interbedded with Deddick Rhyodacite. It outcrops in the Little River Gorge and extends northwards to Wheeler's Creek, averaging about 100 ft. thick. It spreads out to cover a comparatively large area and attains considerable thickness. Its contacts with the basement rock are steeply dipping and often sheared. It is hard to say whether it is intrusive at this locality, or whether its outcrop is defined by subsequent faulting.

The other two flows occur near the top of the Snowy River Volcanics. One flow is about 50 ft. thick and occurs interbedded with tuffs. The tuffs have been folded subsequently and the outcrop of the flow now possesses a "double-S" shape (see Fig. 1). The second flow outcrops along Wulgulmerang Creek between the Deddick and Black Mountain roads. It is the most recent member of the Snowy River Volcanics in this area. There are two outcrops close together, covering about a square mile.

The basal flow is a dark porphyritic rock containing phenocrysts of felspar up to 2 mm. across, set in a dark groundmass. (Hand specimens H4, H5, H6, H7.) The slides (Nos. 7681, 7682, 7683, 7684) show that the phenocrysts consist of euhedral albite $Ab_{96}$ $An_4$. They are usually strongly sericitised or kaolinised. Ferromagnesian phenocrysts are rare, and are completely altered to chlorite or epidote. The originals appear to have been hornblende and biotite.

Quartz occurs very rarely as small partly resorbed phenocrysts in some of the sections and in the groundmass of Nos. 7681, 7682. There is, however, insufficient quartz present to justify calling most of these rocks quartz latites, although No. 7679 has sufficient quartz to come into that category. The groundmasses of Nos. 7683 and 7684 are dark cryptocrystalline devitrified glasses. However, in slides 7681 and 7682 the groundmasses tend to be microcrystalline and consist of alkali felspar, some quartz, and chloritic material.

Slides 7678, 7679 and 7680 come from the top flow. The rock is much the same. The albite phenocrysts tend to be larger, however; up to 3 mm. across. In slide 7678 the groundmass tends to have a trachytic mixture. In the others, however, it is largely cryptocrystalline.

*Sedimentary Rocks*

Interbedded with the lava flows are numerous bands of sediments and pyroclastic rocks. They may be grouped as follows:

Sandstone
Shale
Conglomerate

Tuffs
Agglomerate
Rhyodacite conglomerate

Of these, the second group is by far the most important, reaching a thickness of 2,000 ft. in the Little River area. The former group occurs very early in the sequence, and consists predominantly of detritus derived from the exposed Ordovician bedrock. Strangely enough, detritus derived from the underlying granodiorite is very rare indeed.

The first group of sediments have evidently accumulated in small lakes formed during intervals in the vulcanism. These lakes have received detritus from the exposed Ordovician rocks probably because these latter tended to occupy the higher parts of the topography due to differential weathering, as occurs at present. Conglomerates with sandstone, quartzite and greywacke pebbles are the most common members. The pebbles are only slightly rounded and have evidently not travelled far. There is little or no sorting. The sandstones and mudstones are of irregular distribution, occurring in lenses in the conglomerate. They show the effects of metamorphism by overlying rhyodacite flows. Slide 7685 is taken from tuffaceous mudstones just below the Black Mountain Rhyodacite near the Sugarloaf. They have been completely recrystallized to a low-grade spotted hornfels. Sandstones and greywackes have been silicified and slightly baked, giving rise to a very hard competent rock, which has become intensely fractured during folding similar to the Ordovician breccias described previously. Conglomerates have behaved similarly. (Slides 7686, 7687; hand specimens J2, J4.) These sections emphasize the lack of rounding of the pebbles, which indicates a nearby source.

A very persistent bed of these sediments about 50 ft. thick occurs immediately above the porphyritic Deddick Rhyodacite and is probably continuous from Wheeler's Creek to Old Joe's Creek, a total distance around the strike of about 8 miles. Smaller lenses of similar sediments are found intercalated with the Deddick Rhyodacite in the vicinity of Little River. The highest stratigraphic position these sediments reach is about 200 ft. above the base of the Black Mountain Rhyodacite—an occurrence which was described previously.

Howitt has described similar sediments from Butcher's Creek (1878) whilst Cochrane and Samson (1947) have also found Lower Devonian sediments near the base of the Snowy River Volcanics near Mt. Tara.

Sediments of the second group—tuffs, agglomerates and rhyodacite conglomerates—occur dominantly at the top of the series, where they reach a thickness of 2,000 ft. They consist mainly of tuffs and rhyodacite conglomerates. True agglomerates are fairly rare. Howitt, in his descriptions, uses the term "agglomerate" to signify any coarse fragmental rock in which are fragments are of rhyodacite. Most of the agglomerates he described are, in fact, conglomerates, containing pebbles of rhyodacite with varying degrees of rounding, in a tuffaceous, water-deposited matrix. Beds which appear to be true agglomerates—i.e., coarse fragmental material ejected by volcanic action—are found rarely along the northern boundary of the fragmental rocks; also occasionally interbedded with Gelantipy Rhyodacite. They can only be distinguished by the complete absence of any rounding on the fragments, which are usually smaller than half an inch in diameter (e.g. hand specimen J17).

Tuffaceous rocks are rare in the lower part of the sequence but become increasingly common higher up. Around Deddick there is one fairly extensive horizon from 25 to 50 ft. in thickness, occurring just below the fine-grained Deddick Rhyodacite. However, the outcrops are discontinuous. It reaches maximum thickness just opposite the Sugarloaf. Apart from this bed, tuffs are absent until the Gelantipy Rhyodacite is reached. Thin beds of tuff and rhyodacite conglomerate occur interbedded in this flow. Overlying the Gelantipy Rhyodacite are the main outcrops of fragmental beds in the area. They occupy a basin-shaped structure measuring about 6 miles in a north-south direction and 3 miles east to west. The maximum thickness of 2,000 ft. is found in the Little River section.

The beds in the basal part of the basin are usually very coarse conglomerates carrying pebbles and boulders up to several feet in diameter, although smaller ones, a couple of inches across, are the most common. These pebbles are dominantly of Gelantipy Rhyodacite. An occasional pebble of granodiorite, slate, sandstone or some other kind of rhyodacite is found. The pebbles display varying degrees of rounding, but mostly it is only slight to moderate, indicating that they have not travelled far. Sometimes they display a crude stratification, with their long axes approximately parallel. They are bound loosely by a relatively small amount of soft tuffaceous matrix. Sometimes, however, this matrix has become silicified and hardened, and the conglomerate as a whole then becomes a very tough and resistant rock. They have been called the Boundary Creek Conglomerates, because of the fine exposures and great thickness at the head of the Boundary Creek Gorge.

The thick beds of coarse conglomerate tend to become finer grained as one proceeds upwards in the succession where fine-grained tuffs become dominant towards the top. However, thin lenses of conglomerate still recur at different places, even near the top. Small flows of Gelantipy Rhyodacite are also to be found interbedded with the fragmental rocks, mainly towards the base.

The thick beds of tuff overlying the Boundary Creek Conglomerates have been called the Wulgulmerang Tuffs. They are usually light-coloured fine-grained rocks, often showing well-developed bedding indicative of subaqueous origin. Apart from a small amount of intermediate tuff associated with the latite flow, and a little basic tuff near the Sugarloaf (slides 7690, 7691), they are all acidic, carrying fragments of quartz, altered felspars and ferromagnesians in a fine-grained matrix (J9, J10). Some of the tuffs have the appearance of arkoses—they are seen to consist of small grains of quartz and felspar closely packed together with little cementing material (J14, J15). When tuffs such as these become silicified they are very difficult to distinguish from normal rhyodacites.

### *Dykes Associated with Snowy River Volcanics*

In the Deddick granodiorite there are three dykes which were mapped first by Ferguson (1899). They are up to 3 miles long and have a variable width, averaging about 50 ft. The strike varies from north to north-west. These dykes have been fractured by tectonic forces but not as strongly as the granodiorite. Petrologically they are extremely similar to the bottom flow of latite stretching from Little River to Wheeler's Creek, and require no further description (slide 7699, hand specimen K6). It is probable that the latter represents the effusive product of the dykes.

Deddick Rhyodacite occurs as dykes in a few localities. The fine-grained variety has been intruded in several places along the major fracture in the granodiorite between the Sugarloaf and the Snowy River. The rock frequently has well-developed flow structures which indicate a westward dip (hand specimen K1, slide 7694). These intrusions are as much as 40 ft. thick in places. Smaller dykes of Deddick Rhyodacite ranging up to about 10 ft. wide also intrude the granodiorite along a general north-west strike. Two have been mapped and it is probable that others occur.

## STRUCTURAL RELATIONS OF THE SNOWY RIVER VOLCANICS

It has been indicated previously that the Snowy River Volcanics rest unconformably upon a bedrock mainly of granodiorite, together with Ordovician sediments. Fig. 4 shows a complete east-west section from Accommodation Creek to the Buchan River. It shows that the volcanics on either side of the Snowy River have been folded into two synclines striking north-south, separated by a partially denuded anticlinal fold, over the Deddick Granodiorite. The dips along the granodiorite-rhyodacite contacts wherever measured have been about 50°, and greater. (Small lenses of bedded tuffs and flow lines provide the most reliable means of estimating dip in the volcanics.) The most important syncline is the one passing through Wulgulmerang. This extends continuously down to Buchan and contains a great thickness of volcanics. At Little River the dip is over 50° at the contact of Deddick Rhyodacite and granodiorite. The dip decreases towards the west and at the base of the Gelantipy Rhyodacite is 30° (given by a small interbedded lens of conglomerate exposed in a road cutting). Using these dips as a basis for calculation, the total thickness of the Snowy River Volcanics at Little River is approximately 10,000 ft.

The fact that these folds rest mainly upon a granodiorite basement raises some interesting structural problems—are these folds due to normal compressive movements with accompanying flowage of the granodiorite basement, or are they due to faulting which has caused high marginal dips? Neither of these explanations in their extreme form fits the facts. The possibility that the granodiorite basement has suffered a large amount of plastic flow is ruled out by the fact that no signs of flowage—e.g. gneissic marginal textures—have been detected.

The faulting mechanism was favoured by Howitt (1876) who advocated the existence of a major fault along the Little River-Suggan Buggan contact. Howitt's main reason for this supposition seemed to be the steeply dipping contact, although he claimed to find evidence of shearing at Suggan Buggan. Ferguson (1899) who later mapped part of the Little River contact found no sign of faulting.

The present work confirms Ferguson's views, although occasionally the contacts may be the sites of faults of small displacement. Places can be found (e.g. about 1 mile north along the contact from Little River) where granodiorite and rhyodacite occur within a few feet of each other, with no sign of strong shearing or brecciation.

Furthermore, it is invariably found that the rhyodacites are unaltered, whereas the granodiorite has suffered contact metamorphism. A group of specimens were described previously (slides 7616-17-18) taken from the Little River and Sugarloaf contacts. These showed that the granodiorites had been strongly altered with some development of muscovite, which can be seen in the hand specimens. In contrast rhyodacite slide 7635 taken from the contact is virtually unaffected, save for slight shearing.

The fact that granodiorite at the contact displays the effects of thermal metamorphism means that there has been little or no relative movement between granodiorite and rhyodacite, and consequently extensive faults cannot exist.

However, along the far west contact on the Buchan River divide, near Seldom Seen Lookout, there is some evidence that faulting has occurred. Extensive true fault breccias (hand specimen A9) of Ordovician rocks occur along the contact. The rhyodacite at the contact is the Black Mountain type; Deddick Rhyodacite does not outcrop. However, farther south at Gelantipy, the contact shows no sign of faulting, and a thin band of Deddick Rhyodacite does occur at the contact. This indicates that the above fault is only of local significance.

The solution to the problem of folding seems to lie rather in a combination of the two mechanisms previously considered. As was mentioned earlier, the granodiorite in the area has been strongly fractured and jointed, and slickensides indicating movement along these fractures are very numerous. The joints are so numerous that it would be impossible in most places to find a 2 ft. cube of granodiorite without a few joints traversing it. In a later section it is shown that this intense fracturing and jointing is of Epi Middle Devonian age. It is therefore very likely that they have been formed under the influence of the tectonic movements during the Tabberabberan Orogeny when the Buchan limestones and underlying volcanics were folded.

Apparently, under the influence of these tectonic stresses, the granodiorite has been shattered into small fragments which have suffered relative displacement. The cumulative effect of all these small displacements has caused considerable net vertical movements, analogous to folding. Thus, under compression, the overlying Snowy River Volcanics have been folded into a normal series of anticlines and synclines whilst the underlying granodiorite basement has also yielded with the same result along innumerable faults of small displacement—i.e., a giant gleitbretter effect (see Fig. 5).

The folding has exerted a differential effect upon the fragmental members of the volcanics and the massive rhyodacites. The latter have yielded by flowage and fracturing to give simple open folds. However, the fragmental rocks near the top of the series have been folded disharmonically within the main syncline.

Disharmonic folding of this type is well exhibited along the road near Wulgulmerang Creek bridge. A north-south section of the tuffs over a distance of a few hundred yards is given in Fig. 6.

This type of folding is reminiscent on a small scale of folding of the Juras type, caused by slipping of an incompetent formation over a rigid crystalline basement, and is closely analogous to it. Disharmonic folding also occurs in the Buchan Limestones which also lie in the core of the syncline (Gaskin, personal communication).

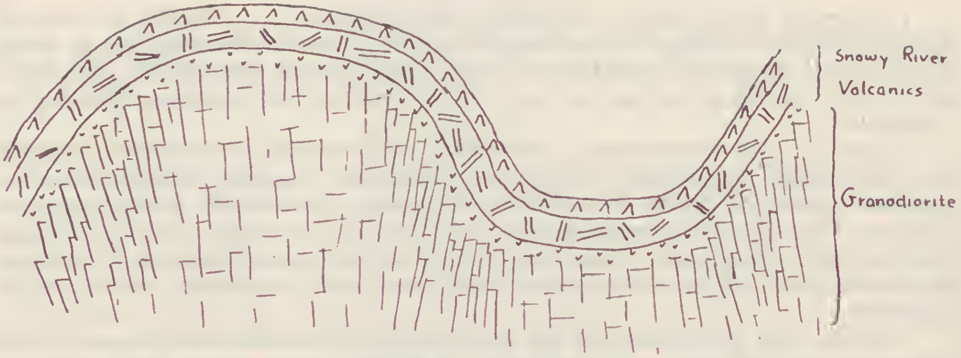


Fig. 5.—"Folding" of Granodiorite and Snowy River Volcanics.

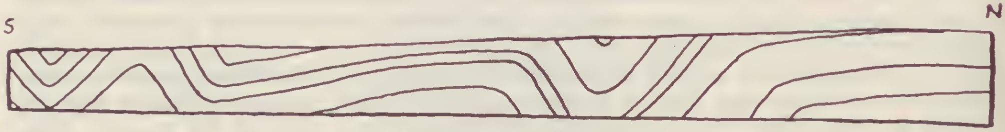


Fig. 6.—Folded Tuffs, Wulgulmerang Creek. Scale 1 in. = 150 ft.

*Mechanics of Extrusion*

It is also clear that another major structure exists within the area. A consideration of the distribution and thickness of the main flows of rhyodacite indicates that a basin-shaped structure existed in the Wulgulmerang-Gelantipy areas prior to folding.

The Deddick Rhyodacite attains a maximum thickness of 3,100 ft. in the Little River area, but this thickness decreases outwards in all directions to a few hundred feet. Overlying this, the Black Mountain Rhyodacite attains a fairly uniform thickness of 2,500 ft. However, the Gelantipy Rhyodacite occupies a distinct basin, the limbs of the syncline converging at Gelantipy. Farther south, near W-Tree, reconnaissance mapping proves that the Gelantipy Rhyodacite thins out considerably and finally disappears. That the fragmental beds occupy a similar, though smaller, basin, may be seen from the map.

This basin-shaped structure is bounded to the north by a fault, which is a major structural feature of the area, and has for convenience been named the Turnback Fault. It has been traced on the surface for 12 miles, and probably extends much farther. South of Black Mountain it strikes roughly east-west, but as it continues towards Wheeler's Creek it veers around to a strike of about 120°. Still farther to the east it veers more, attaining a strike of 150° near the Sugarloaf, where it disappears beneath the rhyodacites, giving it an arcuate shape. From Wheeler's Creek almost to the Buchan Divide it can be traced continuously. Similarly, from the Sugarloaf to the west margin of the Black Hills where the road enters the Ordovician. However, between this point and Wheeler's Creek, a distance of about 2 miles, the fault could only be picked up in one place—on the spur leading to Mt. Turnback from the 8 mile post on the Deddick road. Here a zone of sheared and silicified rock about 10 ft. wide traverses the granodiorite along a north-west strike (slide 7629 and hand specimen B21). Numerous other evidences of shearing, e.g. large xenoliths of sheared hornfels (slide 7613, hand specimen A11) are found in the granodiorite nearby. It was not possible to make a detailed search for the fault in the rest of the area because of the steepness of the hillsides and paucity of outcrops.

The dip of the fault is steep to the south, and south-west. This is demonstrated in three localities.

(i) Near the Sugarloaf it crosses a steep spur, and the outcrop shows pronounced vee-ing, indicative of a steep south-westerly dip.

(ii) Near the Black Hills it is intruded by Deddick Rhyodacite which has well-developed flow structures dipping at 70° to the south-west.

(iii) Near Goodwin's Creek, vee-ing of outcrops again indicates a westward dip.

Where it traverses granodiorite, the Turnback Fault may be recognized by a zone of shearing and brecciation up to a hundred feet wide. This is sometimes intruded by Deddick Rhyodacite. These relations are well exhibited between the Sugarloaf and the Black Hills. Hand specimens K2, K3, K4, K5 and slides 7695, 7696 and 7697 display well the intense brecciation. Fragments of Ordovician quartzites, shales and greywackes, the significance of which was discussed earlier, together with fragments of granodiorite, are enclosed in a matrix of mylonitised granitic material. No. 7694 is a slide of an intrusion of fine-grained Deddick Rhyodacite in the fault. It displays well the flow texture. The intrusions of Deddick Rhyodacite are found between the Sugarloaf and the Black Hills. They range up to 50 ft. thick and are discontinuous along the strike, rarely more than a couple of hundred yards long. The fault merges into the south-west border of the Black Hills hornfelses and continues along this contact for a considerable distance, at least as far as the road. No intrusions of Deddick Rhyodacite are found along this granodiorite-hornfels contact, but intense jointing and fracture of the granodiorite parallel to this contact shows its true nature.

In the Snowy River Volcanics, the existence of the fault is clearly disclosed by the geological mapping. Actual physical manifestations are not so easy to recognize because of widespread shearing of the volcanics due to folding. This makes it difficult to be sure that shearing along the fault zone is always due to the Turnback Fault. Intense shearing is, however, displayed by the Gelantipy Rhyodacite above Wheeler's Creek and also other volcanics in Wheeler's Creek. The thin band of Gelantipy Rhyodacite which occurs along the fault is also strongly sheared.

The basin-shaped structure in the Snowy River Volcanics which was described previously is abruptly terminated in the north by the Turnback Fault. A consideration of the mapping indicates that the south-west block has moved downwards, making it a normal fault. The maximum amount of displacement at Wulgulmerang has been of the order of 7,500 ft. A further fact of fundamental importance emerges—the Faulting was synchronous with the extrusion of the volcanics and is therefore intimately related to the mechanism of extrusion. The basin-shaped structure is of primary origin and has been caused by sinking of the down-thrown block of the Turnback Fault at the same time as extrusion. These facts are established by the following data.

(i) Deddick Rhyodacite has been intruded along the fault at Deddick.

(ii) Near the Sugarloaf, the fault disappears under rhyodacites. The thickness of Deddick Rhyodacite north of the fault is only 200 ft. However, south of the fault, on the down-thrown side, the thickness increases suddenly to at least 2,000 ft.

(iii) At Little River, the thickness of Deddick Rhyodacite is 3,100 ft. This is on the down-thrown side of the fault. North of the fault, towards Suggan Buggan, its thickness is at the most 200 ft.

(iv) The Black Mountain Rhyodacite is widespread on both sides of the fault, and appears to maintain a fairly constant thickness of 2,500-3,000 ft.

(v) The Gelantipy Rhyodacite and the overlying fragmental rocks attain a total thickness of 4,700 ft. on the down-thrown block. They extend continuously to the fault where they are cut off completely. No Gelantipy Rhyodacite or fragmentals have been found on the up-thrown block.

These facts prove that there have been two distinct phases of faulting. During the first phase, the Deddick Rhyodacite has apparently risen up the fault plane and flooded the basin on the down-thrown side to a maximum thickness of 3,100 ft. There was enough rhyodacite to fill the basin and spread out in a thin sheet over an extensive area. No movement of the Fault occurred whilst the Black Mountain Rhyodacites was extruded and it was thereby enabled to cover a large area to a uniform depth. The second phase occurred whilst the Gelantipy Rhyodacites and fragmental rocks were formed. These accumulated in the basin on the down-thrown block to a total thickness of 4,700 ft., and therefore the total throw during the two phases around Wulgulmerang must have been about 7,800 ft.

Most of these general relations are depicted in Fig. 7—a north-south section from the Cobberas to Murrindal.

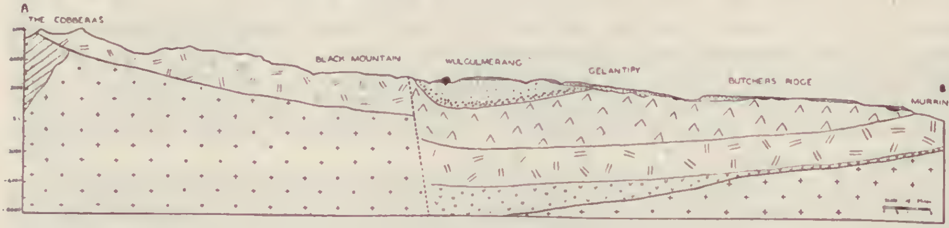


Fig. 7

It cannot be demonstrated conclusively that the major part of the Snowy River Volcanics has been extruded from the Turnback Fault. This is because most of the fault lies through the volcanics, and it is impossible to tell whether the rhyodacites along its course are of intrusive or extrusive origin. However, it seems likely that extrusion of large flows of rhyodacite did occur from this fault in view of the following points.

(i) Its general structural relations which have just been described.

(ii) Around Deddick, where it passes through the granodiorite basement, there are considerable intrusions of fine-grained Deddick Rhyodacite along its course.

(iii) In this general district, the flows of rhyodacite reach their maximum thickness (due to the subsidence caused by the fault synchronously with extrusion). The flows thin out (except Black Mountain Rhyodacite) in all directions outwards from Little River. This suggests that the principal locus of extrusion is in the district. The only feature which could be responsible for extrusion which has been discovered is the Turnback Fault.

(iv) Furthermore, several smaller flows of limited extent occur close to, or along the Turnback Fault. There do not seem to be any obvious feeders which are responsible for them, and accordingly it seems likely that they have been formed by volcanic processes originating from the Turnback Fault. These flows are the upper latite flow and the upper Minor Rhyodacite, at Wulgulmerang, the latite at Wheeler's Creek, the second flow of Minor Rhyodacite at Deddick, and also the tuffs near the Sugarloaf at Deddick.

Although it is believed that the major part of the extrusion came from this fracture, it seems clear that there must have been other smaller loci of extrusion. For example, the three latite dykes, which cover a total length of about 7 miles, appear to have acted as feeders for the latite flow interbedded with the Deddick Rhyodacite. Two other rhyodacite dykes have been mapped and these probably acted also as small feeders. It is highly significant that all these dykes are on the down-thrown side of the Turnback Fault and are closely parallel to that major structural feature. This suggests a genetic connection.

It is probable that there have been several other minor loci of eruption, which have not been discovered. This is suggested by the occurrence of small interbedded flows of rhyodacites and tuffs which lense out in all directions and which appear to be isolated from one another, and for which no feeders have yet been found.

### *Formation of Turnback Fault*

The occurrence of a large arcuate fault along which the inside block moved downward, accompanied by extrusion of great volumes of rhyodacite, immediately suggests cauldron subsidence as the mechanism of extrusion. However, this cannot be so, since the fracture dips in towards the sunken block, which would render impossible the sinking of a large complete block.

In view of this fact, a form of fissure eruption seems indicated. It remains, however, to explain the strongly arcuate nature of the fissure. This is partly due to the influence of existing geological structure prior to faulting—part of the fault is along the junction of two separate phases of the granodiorite intrusions, which are partly separated by an Ordovician screen. However, this cannot be the whole story—it does not, for instance, explain the arcuate dykes of latite in the sunken block which run parallel to the main fracture.

It is possible that the arcuate fault could be explained as due to the action of an asymmetric magma chamber. In view of the eruption of great quantities of effusive rocks, it seems likely that a magma chamber of large extent existed below, in the crust. If such a magma chamber of irregular shape exerted much hydrostatic pressure near its roof, considerable unbalanced stresses would be generated in the roof, and this may result in fracture. This matter has been considered by Emmons (1937), more especially with regard to the formation of vein systems.

Fig. 8 shows the components of stresses which would be set up in the roof of an asymmetric intrusion. It is clear that these stresses would be unbalanced, and that the roof would fracture in the direction indicated if the hydrostatic pressure of the magma was great enough. Furthermore, if the crest of this asymmetric magma chamber possessed an arcuate shape, the outcrop of the fracture formed would also be arcuate. It is suggested that the Turnback Fault is due to such a mechanism. The fracture would initially be a steeply dipping reversed fault, as may be seen from the diagram showing the principal stresses.

This fracture would open the way for extrusion of rhyodacite, which occurs predominantly from the main fracture, and also to a small extent from lesser frac-

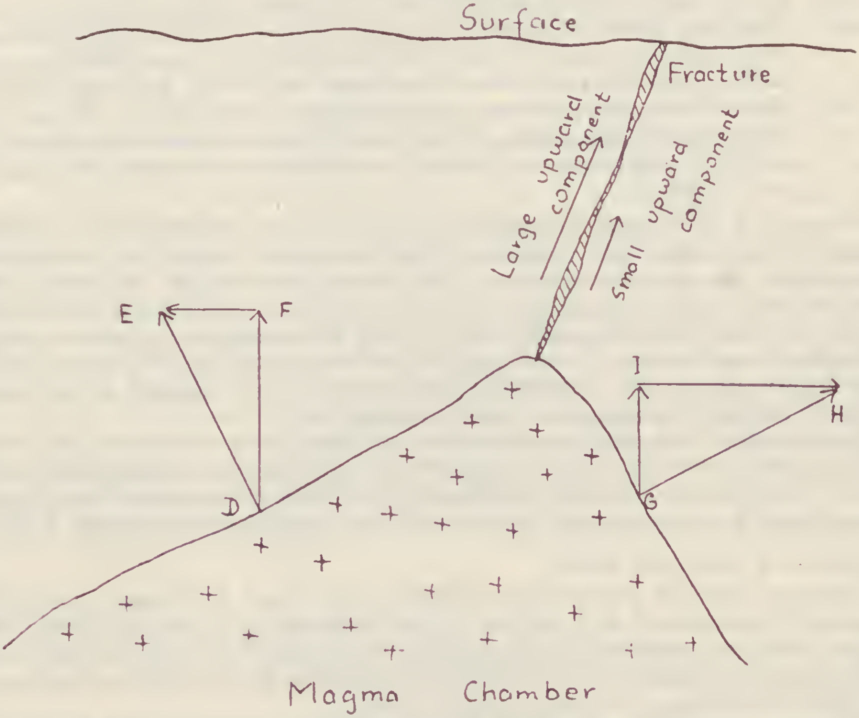


Fig. 8.—Showing resolved components of forces acting on walls of an asymmetric magma chamber under hydrostatic pressure. Unbalance upward components cause fracture. (Modified after Emmons, 1937, p. 24)

tures formed synchronously with the main fracture. Immediately the nature of the fault changes. As extrusion occurs, the pressure on the upthrust block is reduced, and it commences to sink, or rather, sag along the fracture, thus making the fracture into a normal fault. With continued extrusion the block sags further and further forming a basin on the down-thrown side into which the effusive rhyodacites flow, finally accumulating in great thickness. It is clear from the stress diagram that when the level of the magma chamber is falling, the block overlying the less steeply dipping side of the magma chamber will sag the most, and will move downwards relatively to the other block.

## PETROGENESIS

At Deddick, the Snowy River Volcanics attain a maximum thickness of 9,500 ft. of rhyodacites and acidic fragmentals, and about 500 ft. of latites. No basic flows occur. The large flows of rhyodacite are all of highly acidic character; judging from similar analysed rocks at Nowa Nowa they all contain more than 70 per cent silica. Linking these with the latites are some small flows of Minor Rhyodacite. These flows vary irregularly in composition from normal rhyodacite to quartz latite. Thus the transitional character of these rocks suggests that the rhyodacites and latites are related by some form of magmatic differentiation.

There are six horizons at which Minor Rhyodacites and latites occur in the area, and they all have one thing in common. Wherever these relatively basic flows occur, they overlie beds of tuffs or sediments. In other words, whenever a more basic flow has been extruded, a considerable time interval has elapsed between the last extrusion of normal rhyodacite and the extrusion of more basic rock. This relation can hardly be fortuitous. It suggests that the mafic rich Minor Rhyodacites and latites have differentiated in some way from the parent rhyodacite magma; differentiation only occurring when an appreciable time lapse has occurred in the extrusion of rhyodacite. A way in which this could occur is described below.

In a preceding section reasons were advanced for believing that a magma chamber had once existed, connected by a conduit (the Turnback Fault) joining the crest to the surface. If, during a break in extrusion (during which tuffs or sediments were laid down) differentiation took place at the roof and margins of the magma chamber resulting in the formation of more basic magma, then at the next period of extrusion, some of this basified magma would come out of the vent first, and form a small flow which would later be covered with normal rhyodacite. Such a process would explain the observed facts, viz.:

(i) The small amount of basified magma compared to normal rhyodacite.
(ii) The frequent and intermittent extrusion of this magma.
(iii) The fact that it has only been extruded after a considerable time break in the extrusion of normal rhyodacite. (Indicating that a certain amount of time is necessary for differentiation to take place.)

Differentiation of this type has occurred in numerous acidic intrusive bodies which possess basified borders and roofs. Syenites, quartz syenites, diorites, quartz diorites, monzonites and quartz monzonites are the rocks most commonly met with in the border and roof zones of acidic batholiths and stocks, although more basic rocks—gabbros and shonkinites—also occur. The relationship between the inner acidic rocks and these marginal, quantitatively unimportant more basic rocks is frequently gradational, and it is reasonably clear that the basified borders have often developed by some process of differentiation from the parent acidic magma.

Accordingly it is suggested that the occurrence of Minor Rhyodacites and latites in the Snowy River Volcanics is due to differentiation of a parent rhyodacite magma —the differentiation taking place near the roof of the magma chamber during intervals in extrusion. The differentiation is exactly analogous to the formation of a monzonitic border and roof phase (latite) to a granodiorite connected by transitional stages (Minor Rhyodacite). Examples of this type of differentiation are Vermilion Batholith (Grout 1925); Newry Granodiorite (Reynolds 1934); Yogo Peak (Weed and Pirrson 1899).

Basic magmas are commonly regarded as being the immediate parents of acidic and intermediate magmas but it would be rather artificial to assume that a basic magma was the immediate parent of the rhyodacites. Firstly, no basic flows occur in the area (although a small flow is found near Buchan). Furthermore, the total thickness of rhyodacite—9,000 ft. as against only 500 ft. of quartz latite—makes it difficult to regard the enormous thickness of acidic rock as derived from the small amount of latite, which was itself derived from a basalt which is not even found. It seems preferable to regard the parent magma as primary in exactly the same sense as the parent magmas of acidic batholiths are being commonly regarded as primary.

## Epi Middle Devonian

The lamprophyre dykes and mineral deposits of the Deddick area are probably of this age. The lamprophyres intrude rhyodacites of the Snowy River Volcanics along the Suggan Buggan road, and also about half a mile east of the Sugarloaf.

The mineral lodes are found to cut the dykes. At Buchan, similar dykes associated with galena deposits are found in the Middle Devonian limestones (Howitt 1878). An upper limit to their age is derived from structural data. The lodes and dykes, together with the granitic country rock of the area, have been severely fractured and deformed. The universal fracturing and jointing has been caused by the Tabberabberen Orogeny (Epi Middle Devonian) which was responsible for folding the Snowy River Volcanics and the overlying limestones.

The dykes and mineral lodes of the Deddick area have been described by several workers—Sterling (1899), Dunn (1909), Jenkins (1899), Ferguson (1899) and Whitelaw (1921), but Ferguson's account is by far the most important and comprehensive. He mapped the lodes and dykes, noting their mutual relations and described the more important lodes. Fig. 2 is based largely upon Ferguson's map of 1899, although the author has inserted several dykes not mapped by Ferguson, together with the Turnback Fault and other details.

## Lamprophyre Dykes

These dykes fall into two distinct groups—biotite monchiquites and spessartites. Biotite monchiquite occurs in only two small dykes, whereas the spessartites form a dense swarm.

### *Biotite Monchiquite*

Two small dykes about one mile north-north-west of the Sugarloaf are found to be of biotite monchiquite. These were discovered and mapped by Ferguson, who called them biotite olivine diabase. They average about 2 ft. wide and cannot be traced more than 100 yds. separately. It is possible, however, that they are connected since they lie on approximately the same strike, parallel to the spessartite swarm. They have been sheared and fractured, and hence are earlier than the Tabberabberan Orogeny.

Macroscopically they are seen to be porphyritic in texture, with phenocrysts of biotite up to ½-inch across, apatite prisms up to ¾-inch long, olivine, and other unrecognizable minerals, sparsely distributed in a fine-grained black groundmass. In one specimen, an inclusion of dunite occurs.

Under the microscope the phenocrysts are seen to consist of biotite, apatite, enstatite, olivine (largely serpentinised), magnetite and rare augite in a groundmass of small augite prisms, magnetite and some olivine set in a glassy base.

Biotite occurs commonly in phenocrysts up to ⅝-inch across. Mostly it occurs in rounded crystals of irregular shape, but sometimes in euhedral crystals of hexagonal outline. It is an iron rich variety with $\eta\beta \simeq \eta\alpha = 1{\cdot}67$ and is pleochroic from green brown to black. The optic axial angle is very small, less than 10° (slide 7704). The phenocrysts are commonly distributed throughout the dyke and show no preferential orientation. Crystals of apatite are commonly included. Some of the smaller biotite crystals are breaking down into aggregates of magnetite, hematite and indeterminate secondary minerals, evidently due to a process of resorbtion. Some large crystals of magnetite associated with a large biotite phenocryst slide 7728 also appear to be derived from the resorbtion of biotite.

The only phenocryst attaining comparable size with biotite is apatite which occurs sparsely throughout the rock in long slender prisms up to ¾-inch long, although the average length would be considerably less than this (slide 7703 and hand specimen L2). Olivine is a very abundant phenocryst although it is usually much altered. Olivine is also an important constituent of the groundmass in which it occurs in small subhedral grains. There is a complete gradation in size between the groundmass olivines and the phenocrysts. A fairly fresh phenocryst in slide 7729 gives a good interference figure, which indicates a very high optic axial angle, close to 90°. The olivine therefore is close to forsterite in composition. Most phenocrysts have suffered considerable secondary alteration, generally to plate-like masses of serpophite, usually surrounded by rims of antigorite. Occasionally carbonates (magnesite?) are present in the cores. Iddingsite is also often present as an alteration product. Apart from the olivine, there is little secondary alteration in the rock. Enstatite occurs sparingly as small phenocrysts up to 1 mm. across, but not in the groundmass. The phenocrysts are small anhedral crystals, surrounded by reaction rims which are usually indeterminate. However, two crystals in slide 7701 show reaction rims of recognizable augite and phlogopite. In Fig. 9a the first stage in the reaction seems to be the formation of a symplekite of chloritic material and crystallites of augite. At a later stage the augite crystallites grow and coalesce. The augite has the same structural orientation as the parent enstatite, and extinguishes uniformly. A couple of incipient crystals of phlogopite are seen in the process of development from the symplekite. In Fig. 9b, the development of phlogopite directly from enstatite is shown. The first stage seems to be the development of a chloritic material along the cleavage and margins of the enstatite, and this later develops into phlogopite. The phlogopite is light green in colour and slightly pleochroic.

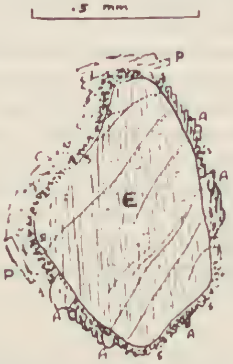


FIG. 9a. — Enstatite (E) with reaction rims of augite (A), and phlogopite (P).
(s)—Symplekite.
(c)—Chlorite and incipient phlogopite.

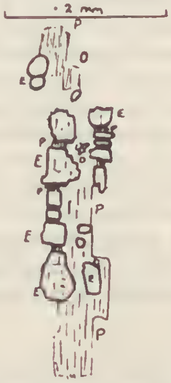


FIG. 9b. — Enstatite (E) with phlogopite (P) reaction rim.

Augite occurs abundantly in the groundmass as small euhedral prisms. It is also found very rarely as small phenocrysts up to ½ mm. across. The groundmass is composed dominantly of small euhedral augite prisms which have an extinction angle of 45°. They lie in an isotropic groundmass which may contain analcite—it has a refractive index less than balsam, and is gelatinised by warm concentrated nitric or hydrochloric acids.

Magnetite is an important constituent of this rock. It occurs both as large "phenocrysts" and scattered thickly throughout the groundmass in small octahedra. An important feature of the magnetite in the groundmass is that it has crystallised before augite. Whenever the two minerals are in contact, it is the augite which includes or tends to include the magnetite. Another unusual feature is the occurrence of magnetite "phenocrysts" with coronas of augite. These "phenocrysts" range in size up to 5 mm. across. They are invariably rounded. Some consist of pure magnetite, whilst others consist of extremely fine intergrowths of magnetite, pyroxene and sometimes other indeterminate minerals. Usually they possess a thin corona of augite which extinguishes uniformly. Sometimes crystals of apatite may occur as inclusions.

There is a gradation in size between the magnetite phenocrysts and the magnetite of the groundmass although it is rather abrupt. There is also a complete gradation between phenocrysts consisting predominantly of magnetite, to those consisting of intergrowths of magnetite and augite, continuing down to the stage where magnetite occurs as inclusions in an augite crystal. Clearly, all these features which have been described are diagnostic of a reaction relationship between magnetite and augite. A series of these intergrowths is shown in Fig. 10.

When some of the magnetite phenocrysts are examined using high-power magnification and intense illumination it is found that they consist of very finely grained magnetite sometimes intergrown with other minerals (e.g. slide 7705). In this slide, near the centre, the magnetite is intergrown with a brown mineral, optically continuous over the whole area, with a moderate optic axial angle, and apparently optically positive. Near the margins, however, this mineral gives way to solid magnetite, which has an outer reaction rim of augite in places. The same features are noticed in some other sections. The concentration of magnetite (or hematite, as in section 7730) is greatest near the margins. Textures such as these are characteristic of resorbed ferromagnesian minerals. (Larsen 1937.)

### *Petrogenesis*

The first point requiring explanation is the origin of the magnetite "phenocrysts". They must have developed at an early stage of crystallization of the magma, since it has been shown that they precede augite. It therefore seems most unlikly that they have crystallized directly from the lamprophyre magma, since magnetite aggregates of this size and texture are never found in the chilled selvages of basic dykes or flows. It therefore seems probable that they represent resorbed phenocrysts of ferromagnesian minerals, or foreign inclusions of unknown origin. Since the dyke has been intruded through a granite batholith, the incorporation of xenoliths of magnetite seems to be ruled out.

Accordingly it appears that the magnetite phenocrysts must be due to resorbtion of ferromagnesian minerals. There are several lines of evidence which suggest that this is the case.

The only mineral in the lamprophyre capable of furnishing the magnetite phenocrysts from the point of view of both size and composition, is biotite. The magnetite phenocrysts are up to 5 mm. across, and are the largest crystals after biotite and apatite. Furthermore, the biotite is an iron rich variety. All other phenocrysts present in the magma are poor in iron (enstatite, forsterite and apatite). That the magnetite is due to resorbtion of biotite is suggested by

(i) both biotite and magnetite intergrowths are approximately of the same range of sizes, and shape. The biotite occurs in rounded crystals of irregular shape as does the magnetite.

(ii) The biotite commonly contains inclusions of apatite. The magnetite also contains inclusions of apatite of similar size.

(iii) Some of the magnetite phenocrysts have a striated appearance, the striae being due to varying content of magnetite and intergrown minerals. This structure is probably derived from the cleavage of the biotite.

(iv) The occurrence of intergrowths with rims entirely of magnetite, whilst the core is composed of magnetite intergrown with some indeterminate minerals is similar to undoubted occurrences of resorbed biotite described by Larsen (1937). Larsen has also described biotite completely replaced by magnetite.

(v) Some small crystals of biotite can actually be observed to be breaking up into aggregates of magnetite, hematite, and other secondary minerals.

In one crystal (section 7703) the magnetite is confined to the margins of an altered biotite crystal.

The question of resorbtion of complex minerals has been fully considered by Bowen (1928). He shows that resorbtion will take place strictly in accordance with the reaction series. A mineral late in this series, if it should sink into a warmer environment in which earlier members of the reaction series are being precipitated, will react and be converted into the phase with which the magma is in equilibrium. This principle fits exactly the case under discussion.

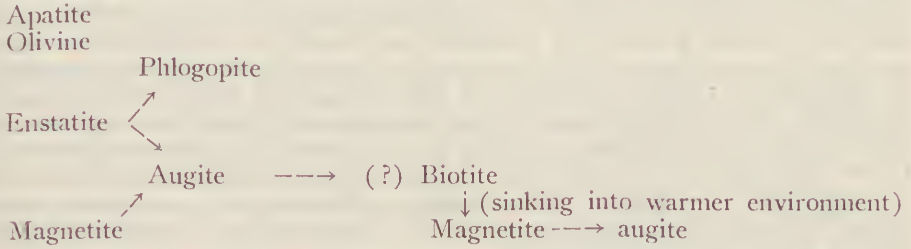
When magma is intruded into a vertical fissure the earlier portions which encounter the cool country rock first will suffer more cooling than the later portions, which enter pre-heated walls. Therefore, the magma at a higher level in a small dyke will be cooler, and therefore at a later stage of crystallization than the magma at lower levels.

In the upper portions of the dyke, the lamprophyre magma had apparently reached a relatively late stage of crystallization, during which large phenocrysts of biotite were forming. These crystals because of their large size and high density would sink very rapidly, and reach lower portions of the dyke which were at a higher temperature and therefore at an earlier stage of crystallization. In this higher temperature region the minerals crystallizing out were magnetite, olivine, enstatite and apatite. Following the principles developed by Bowen, the biotite which is iron rich has reacted with the residual magma to precipitate not olivine or enstatite which are poor in iron but magnetite.

At a later stage of crystallization, magnetite has ceased to crystallize, and a reaction relation has developed between magnetite and augite. The phenocrysts of magnetite are partially resorbed and rounded, and develop reaction rims of augite. In other cases, the reaction has occurred in the magnetite phenocryst between the grain boundaries, resulting in an intergrowth of magnetite and augite. There are all stages of transition between magnetite phenocrysts with small reaction rims, through magnetite-augite intergrowths, to almost pure augite (Fig. 10).

Thus, crystallization has been dominated by a reaction series similar to that proposed by Bowen. However, there is no evidence of a reaction of olivine to give enstatite. These two minerals appear to have separated simultaneously.

*Crystallization of Biotite Monchiquite Dyke*



In the mechanism proposed above, it should be pointed out that the distance which the biotite would need to sink would be only of the order of a few feet.

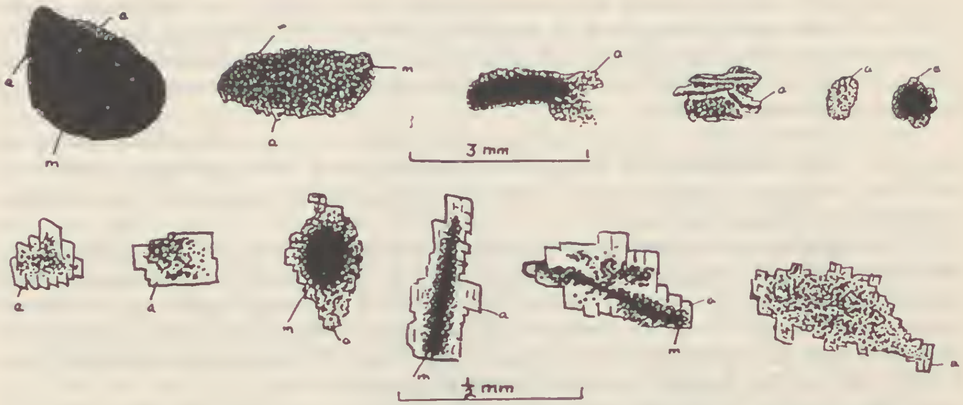


FIG. 10.—Intergrowths and reaction rims of magnetite (m) (black) and augite (a).

The small thickness of the dyke (2 ft.) ensures that rapid cooling with high temperature gradients has taken place. Therefore the biotite would not sink far before encountering a warmer environment.

The mechanism has two implications which require discussion.

The first is that magnetite may in some conditions form an essential part of the discontinuous reaction series of ferromagnesian minerals. As far as the biotite monchiquite cited above is concerned, this contention may be regarded as proved. It seems possible, however, that the magnetite-augite reaction may be more widespread than is sometimes realized. The widespread occurrence of the reverse reaction —the resorbtion of ferromagnesian minerals to precipitate magnetite—is well established. There does not seem to be any *a priori* reason why the resorbtion process should not proceed in the opposite direction with equal facility.

The phase relationships of the ternary system $Na_2SiO_3$-$Fe_2O_3$-$SiO_2$ have been investigated by Bowen, Schairer and Williams (1930). They have demonstrated the existence of a reaction relation between hematite and acmite. In their discussion of that system they suggest by analogy that magnetite may possess a reaction relation to other ferromagnesian minerals. In support of this contention they point out that many ferromagnesian minerals when melted furnish magnetite, "a fact which suggests that magnetite has the same relation to these minerals that hematite has to acmite". This prediction has been completely verified in the biotite monchiquite described above.

Since the magnetite phenocrysts in this rock are reacting to produce augite it follows that the magnetite of the groundmass which crystallized early must also be reacting. A cursory examination does not disclose any obvious reaction relationship between the groundmass magnetite and augite—no signs of resorbtion or coronas. However, more careful observation discloses that a large percentage of the magnetite is closely associated and often included in augite. Where magnetite is densest, very often the augite is also concentrated. Taken by itself, this observation would not be sufficient to establish the existence of a magnetite-augite reaction. However, because of the reasons enumerated previously a reaction must be occurring. It is advisable to remember Bowen's dictum—the fact that one mineral does not display the corona relation to another is no indication that a reaction relationship between the two is not present.

Considerations such as these suggest that early magnetite may often possess a reaction relation to other ferromagnesians without it having been noticed. This applies particularly to basic magmas somewhat richer than usual in alkalis. In magmas such as these, magnetite is often a mineral of early crystallisation, whereas in normal subalkaline basic magma it usually crystallises late.

Bowen, Schairer and Williams' discussion (1930) of the possible courses of crystallisation of the system $Na_2SiO_3$-$Fe_2O_3$-$SiO_2$ make it clear that a magnetite-augite reaction could be of considerable importance in governing the crystallisation and subsequent differentiation of basic alkali rich magmas.

A second implication of the mechanism previously put forward to explain the existence of magnetite phenocrysts is that the biotite phenocrysts crystallised completely within the dyke, and are not of intratelluric origin. In this particular case, it was not possible to obtain a sample of the chilled border zone, and so no definite decision can be given for this particular dyke. However, it might be noted that the biotite phenocrysts show no preferential orientation parallel to the walls of the dyke. If these phenocrysts had been present when the lamprophyre was emplaced it is to be expected that they would show some preferential orientation due to flowage of the magma through the narrow dyke channel.

Some workers (e.g. Bowen 1929) are inclined to infer from the typical panidiomorphic and porphyritic textures of lamprophyres that the initial magma has never existed completely in the liquid state. However, occurrence of a chilled glassy border phase in the lamprophyre described by Campbell and Schenk (1950) show that this is not so. In a camptonite dyke 3 ft. wide, phenocrysts are absent in the chilled border phase, but hornblende phenocrysts increase in size regularly towards the centre where they reach four inches in diameter. The chilled border phase contains only a few crystals of magnetite and olivine.

Actually there is nothing to suggest that these strongly porphyritic textures cannot be explained in terms of current concepts of crystal growth from liquid mediums.

Winkler (1949) has studied the relation between rate of crystallisation and size of crystals for nepheline crystallising from a melt. Measurements of crystal size in a basic dyke (Fig. 11) showed that other minerals follow the same shaped curve. Winkler believes it holds for all crystals.

It will be observed that when a magma cools slowly (e.g. under plutonic conditions) the crystal size is usually not very coarse (pegmatites excepted). However, there is a narrow range of rapid cooling during which crystals very much larger than average size separate. With extremely rapid cooling, the crystal size decreases very rapidly, and a glass may result. The position and magnitude of the high growth rate region depends upon the individual mineral and its environment (especially viscosity). It appears that in lamprophyric magmas which are usually rich in volatiles, and therefore of low viscosity, this high growth rate for ferromagnesians occurs under conditions where the rate of cooling is very high, as would occur in dykes of moderate thickness.

In the dyke described by Campbell and Schenk the conditions are represented by the right hand side of the curve in Fig. 11. The glassy selvage represents the extremely high rate of cooling, whereas the hornblende phenocrysts in the core have been formed under critical conditions near the crest of the curve. On the other hand, in a dyke described by Winkler (1949) the full curve is represented.

It would therefore appear that the texture of the biotite monchiquite described can be explained satisfactorily in terms of rapid crystallization of a magma of low viscosity without introducing assumptions about intratelluric origin of phenocrysts.

Another argument which has been used to support the contention that lamprophyres do not in general crystallize from liquids of their own composition is the fact that the ferromagnesian phenocrysts frequently display signs of resorbtion, and hence cannot be in equilibrium with the surrounding liquid. However, as was pointed out earlier, this is to be expected, since the phenocrysts will tend to sink in the dyke, reaching warmer zones which are not yet in equilibrium with the phenocryst. Consequently some resorbtion occurs. This has occurred in the biotite monchiquite described causing formation of magnetite phenocrysts. A biotite phenocryst which has become much rounded and partly resorbed is shown in slide 7702.

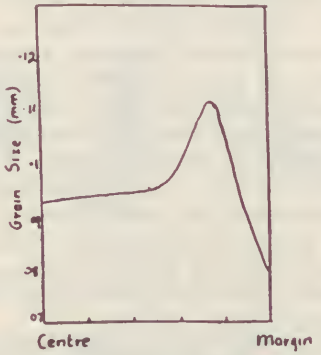


Fig. 11.—Grain size variation of augite in Cleveland Dyke.

(*After Winkler 1949, p. 568.*)

### *Spessartites*

A swarm of spessartite dykes occur within the area. They are found in a zone between Wheeler's Creek and the Sugarloaf. The great majority possess a north-north-west strike and a vertical dip. All except one of the dykes occur to the west of the Turnback Fault, and increase in density as the fault is approached from the west. The dykes range from 6 inches to 20 feet in thickness and are up to 2 miles in length.

Hand specimens reveal the spessartites to be fine-grained greenish rocks occasionally showing a small phenocryst of felspar or altered ferromagnesian minerals. Small isolated crystals of arsenopyrite, pyrite and chalcopyrite are widely distributed. Sometimes barite and galena are found along mineralized shear planes.

Petrology. M1 is a fairly typical spessartite. The hand specimen shows it to be a fairly fine-grained speckled green rock with occasional phenocrysts of felspar. Small patches of calcite occur, as does also an occasional patch of chalcopyrite. The slide (7707) reveals phenocrysts of felspar and altered ferromagnesian minerals lying in a groundmass of felspar laths, chlorite, magnetite, augite, epidote and calcite.

The felspar phenocrysts range in size from 1 mm. downwards, and are transitional in size with the felspars of the groundmass. They are euhedral-subhedral in habit and are usually partly kaolinised. The felspars, both phenocrysts and groundmass, consist of albite and orthoclase in sub-equal proportions. The albite is a sodic variety and has a composition of about $Ab_{96}An_{4}$.

Ferromagnesian phenocrysts are widely distributed but apart from some exceptionally fresh augites, they are completely altered—mainly to chlorite and epidote. Judging by the shape of the pseudomorphs the original large phenocrysts were mainly of hornblende, although the fresh ferromagnesians are of augite. The phenocrysts are up to 3 mm. across and are nearly always altered to antigorite. One large phenocryst has been completely epidotised.

The larger phenocrysts have suffered considerable resorbtion and have reacted with the magma to precipitate alkali felspar, which may form coronas. The resorbtion of ferromagnesian phenocrysts in lamprophyres has been discussed previously, and the cases in point may be explained by mechanisms similar to those suggested. In this case, however, the initial alkalic content of the hornblende has been precipitated as alkali felspar when resorbtion occurred, instead of passing into the residual liquid (Fig. 12).

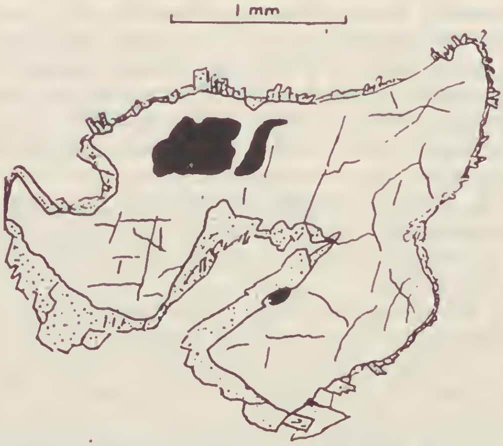


FIG. 12.—Showing corona of alkali felspar (stippled) surrounding epidotised augite (?). Black: iron ore; shaded: zircon.

In other cases, resorbed phenocrysts are surrounded by a corona of extremely minute felspar prisms embedded in chloritic material. In one case, quartz occurs within the core. This appears to be another example of resorbtion.

Slide 7710 is from another spessartite which has suffered more extensive secondary alteration. Large amounts of calcite are disseminated throughout the rock. Small interstitial anhedral crystals of quartz, often showing undulose extinction, are widely distributed. They appear to have been introduced later and sometimes are seen to be replacing felspar. In slide 7711M a large crystal of arsenopyrite is seen. It has moulded itself partly around a small felspar phenocryst, but it seems to be earlier than the groundmass felspars which are curved around it in a flowage structure.

No. 7708 is a slightly different variety, consisting of a few phenocrysts of oligoclase $AB_{87}An_{13}$ up to 1 mm. across and an occasional altered femic phenocryst, lying in a groundmass of orthoclase, oligoclase, chloritised femic material, abundant magnetite and calcite. The felspar laths of the groundmass are mainly orthoclase and are arranged in trachytic texture. The femic constituents (apart from a little unaltered augite) are always altered and partly resorbed. The remains of one large phenocryst 5 mm. long, probably originally of hornblende, are recognizable only by a concentration of iron ore, chlorite, and minute felspar prisms. Some of the secondary calcite is apparently of late introduction—a veinlet of that mineral traverses the slide.

*Mineral Deposits*

Within the area a large number of mineral lodes occur. About 80 have been mapped by Ferguson. These lodes occur exclusively within the granodiorite; none have been found in the Ordovician sediments or in the Snowy River Volcanics. The distribution of the lodes within the granodiorite reveals some features of interest. On the western, or down-thrown, block of the Turnback Fault, the lodes occur widely distributed throughout the granodiorite but increase in density as the fault is approached. On the eastern side of the fault, no lodes occur. It is therefore clear that the Turnback Fault has been the important structural feature governing the distribution of the lodes. (It will be recalled that almost exactly similar relations apply to the distribution of lamprophyres.) (See Fig. 2.)

The lodes possess two dominant strikes. The most important by far is a N.W.-N.N.W. strike. This is also the strike of the lamprophyres, and the Turnback Fault, and the principal strike of the latite dykes. It is interesting to note that as the Turnback Fault swings around from a N.N.W. strike towards a N.W. strike, the strike of lodes and dykes swings around so that they remain parallel to the fault.

The N.W. striking lodes are often very persistent, and can sometimes be traced for upwards of a mile. Another smaller set of lodes possesses a dominant E.-W. strike. These are typically short, and are restricted in occurrence to a long narrow zone of granodiorite close to the Turnback Fault. The significance of these structural relations will be discussed later.

The lodes occupy true fractures along which considerable movement has often taken place. Slickensides indicating horizontal movement are very common, although rarely they indicate vertical movement. The dip of the lodes is mostly vertical although divergence from this dip up to 20° often occurs. The thickness is very variable, ranging from a fraction of an inch up to 3 ft. Large variation of thickness may occur within a short distance. Sometimes a lode consists of one principal fracture, whilst at other times there may be a number of anastomosing mineralized fractures forming a stockwerke—as at the James Lode, in the northern tunnel.

The minerals which have been introduced comprise mainly quartz and galena, with lesser quantities of barite, calcite, sphalerite, pyrite, chalcopyrite and arsenopyrite. These minerals have been introduced into the fissures by the mineralizing solutions and have been deposited mainly by replacement of wall rock. (Slides 7713-7724.) Filling of open spaces has been of minor importance, although it is noticeable locally—e.g., a small offshoot of the United Lode has a large number of vughs and open spaces which have been partly filled by quartz, barite and galena.

The sulphide minerals occur in shoots, of which there is never more than one along any mineralized fracture. The shoots of ore are usually very narrow and irregular in width. In places, as at the James, United and Begelhole lodes, sulphides may be distributed through sheared granodiorite over a width of about 3 ft., and yet in a distance of only a few yards from such occurrences, the lodes may have thinned out to a few inches.

In places, the lodes contain bulges of massive galena up to a foot wide, but they are usually small. The largest bulge occurred at the Eastern Lode, where pure galena, 1 ft. wide, extended for 60 ft. Other rich pockets occur at the James and United Lodges, but they are much smaller. Wherever these bulges occur, there are practically no gangue minerals; however, in places where galena is disseminated through the sheared and altered granodiorite, large amounts of quartz are always present.

WALL ROCK ALTERATION. The solutions which have carried the sulphides have altered the wall rock for distances from 2 ft. to 20 ft. from the fracture. The width of the zone of alteration is closely connected with the amount and intensity of minor fracturing associated with the main fracture. The alteration is predominantly sericitisation of wall rock, followed by silicification.

The wall rock alteration may be conveniently divided into three zones.

Zone 1. For considerable distances on either side of the lode, sericitisation of andesine in the granodiorite has occurred, e.g. slide 7713 taken 20 ft. from the United Lode. Orthoclase and quartz are unaffected, but biotite is bleached and chloritised. Closer to the lode, orthoclase becomes kaolinised (slides 7714, 7715, 7716).

Zone 2. Immediately next to the lode, usually with a thickness of a few inches but occasionally up to 3 ft. wide, is a zone of intensely strong sericitisation. The partly kaolinised orthoclase is almost completely replaced by sericite. Andesine is completely sericitised, but relics of chloritised biotite remain (slides 7719, 7720). Secondary muscovite is developing in many places. The hand specimen (N7) is a characteristic soft greenish rock of granular texture with small visible flakes of muscovite.

Zone 3. This zone comprises the mineralized rock which constitutes the lode proper. It is characterized by the introduction of quartz and sulphides, and then subsequent replacement of the sericitised sheared granodiorite described in zone 2 (slides 7717, 7721). Slide 7717 displays well the selective replacement of sericite by galena. The permeability and large surface area of the sericite has probably caused galena from the mineralizing solutions to be precipitated by sericite more so than quartz. Slides 7717 and 7721 indicate that fracturing has occurred whilst deposition of quartz was taking place. Small veinlets of quartz cut sharply across the earlier generation of quartz which is replacing sericite. In slide 7721, galena occurs in the centre of the veinlet. In all slides where galena occurs in close association with quartz it is seen to be later than the quartz and replacing it.

Most students of ore deposition attribute the sericitisation of wall rock so common in mineral deposits to the effect of hot alkali bearing solutions which transported the sulphide minerals. Analyses usually indicate that large amounts of potash are added to the wall rock during the process of sericitisation. The fact that in the case just described, the andesine has been most susceptible to sericitisation, and not orthoclase, which is only sericitised at a much later stage, suggests that the solutions carried potash. Furthermore, the development of muscovite close to the lodes suggests that the sulphide bearing solutions were at a fairly high temperature (Lindgren, 1933).

The fact that kaolinite is one of the main alteration products indicates that the mineralizing solutions were of acidic character (Gruner, 1944). Since sericite has been formed (in the outer zone of alteration) at the same time as kaolin, it would seem that the solutions have not, however, been very strongly acidic.

In hot, slightly acidic environments, whether felspar alters to sericite or kaolinite is determined by the concentration of the potassium ion (Gruner, 1944). Since most of the orthoclase in the zone next to the lode has been sericitised, whilst further out the orthoclase has been kaolinised, it would appear that most of the potash introduced by the mineralizing solutions has been fixed in the sericitised country rock nearest to the lode. The alteration further out has been caused by solutions poorer in potash, which have therefore kaolinised the orthoclase. However, they must have contained some potash, since the andesine has been sericitised to a larger extent.

The Eastern Lode cuts a lamprophyre dyke. For some distance along the dyke on the north side of the intersection, the lamprophyre has been considerably altered. Quartz and galena have been deposited throughout the body of the rock, forming a low grade ore. The alteration is displayed in slides 7723 and 7724. The lamprophyre was evidently a mica bearing variety, since the chloritised remnants of numerous crystals of biotite are present. Apart from the biotite, the remainder of the rock has been altered to a fibrous aggregate of some micaceous mineral. This mineral possesses a high relief and forms small prisms averaging 0·1 mm. long. Its birefringence is low, resulting in a first order yellow. It is coloured pale green, possesses slight pleochroism, has a perfect cleavage, and is length slow. Antigorite is the mineral which fits this description best, but the high relief displayed by the mineral seems to rule antigorite out. Nevertheless, it is probably some other kind of chlorite or serpentine mineral.

It is being replaced by quartz, which occurs widely throughout the rock, both disseminated, and occupying fractures. Slide 7724 shows a further stage of replacement. Large euhedral crystals of quartz are replacing the antigorite (?), and moulded on to the hexagonal crystals of quartz, and enclosing some, is a large crystal of galena, which is clearly later than the quartz. The quartz crystals exhibit an interesting growth phenomenon (Plate III). At an intermediate stage of growth, a euhedral crystal of quartz has incorporated a border of inclusions. Previously, the quartz had been quite uniform. However, incorporation of these inclusions has altered the nature of the radial growth, giving it a radial comb structure, which nevertheless preserves a perfect hexagonal outline.

PARAGENESIS. The mineral assemblage of the lodes is limited. Galena is by far the most common sulphide mineral. Other sulphides present are sphalerite, chalcopyrite, pyrite and a minute amount of arsenopyrite.

A study of polished and thin sections indicates that the sulphides, together with gangue minerals, were deposited in a definite order, as follows:

Quartz
Period of Fracturing
Quartz
Pyrite, arsenopyrite
Sphalerite, chalcopyrite
Galena
Period of Fracturing
Pyrite

Apart from the late generation of pyrite, this sequence of deposition is the same as that occurring in most ore deposits.

The existence of the first period of fracturing is demonstrated in slides 7721 and 7717, where veinlets of quartz cut other quartz which is replacing sericite. The existence of a second period of fracturing is indicated in polished section No. 1. Veinlets of pyrite are observed to cut galena and sphalerite.

In the polished section examined, chalcopyrite occurred in small amounts as ex-solution bodies in one of the specimens of sphalerite. The other specimens contained no chalcopyrite. This mineral, however, occurs in massive form at the Begelhole Lode, associated with galena and sphalerite.

TEMPERATURE OF DEPOSITION. The existence of numerous ex-solution blebs of chalcopyrite distributed randomly throughout some of the sphalerite from the United Lode furnishes a valuable criterion of deposition temperatures. Since solid solution of chalcopyrite in sphalerite only occurs above 350°-400° C. in appreciable amounts, the above temperatures are the minimum temperatures at which the sphalerite was deposited.

Considering their geological situation, the depth of deposition of the ores would almost certainly be less than 15,000 ft., allowing for the probability of 10,000 ft. of volcanics, 3,000 ft. of Buchan Limestone, and a couple of thousand feet of Upper Devonian sediments overlay the granodiorite at the time of deposition. Assuming a normal thermal gradient the temperature at this depth would be about 160° C. It is therefore clear that the mineralizing solutions have been derived from a source which was considerably warmer than the surrounding country rock. An igneous source would therefore seem to be necessary.

RELATIONS OF LODES AND DYKES. Actually there is ample field and mineralogical evidence which strongly suggests that the process of ore deposition was intimately connected with the lamprophyre dykes. The evidence for genetic association of ore deposits with these dykes may be briefly stated.

(i) The ore deposits and dykes are closely connected in time. Both are very probably post Middle Devonian, and were emplaced before the conclusion of the Tabberabberan Orogeny (see later section). The lodes are later than the dykes, transgressing them at intersections.

(ii) Dykes and lodes exhibit a regional association. At Deddick there is a close spatial connection. Farther south in the granite at Campbell's Nob, the author has found similar lamprophyres in close relation to galena bearing lodes. In the limestones at Buchan and Murrindal, Howitt has described deposits of galena which have formed along and close to similar lamprophyres which intrude the Middle Devonian Limestones. The area between Deddick and Buchan seems to constitute a mineral province characterized by lead mineralization and lamprophyre dykes.

(iii) Dykes and ore deposits at Deddick show a close structural relation. They occupy the same system of fractures controlled by the Turnback Fault—some fractures being taken by dykes and others by lodes. Sometimes lodes form along dykes. To quote Ferguson (1899), who fully recognized this relationship, "where there are most dykes, there are most lodes".

(iv) The dykes commonly carry small quantities of sulphides, principally pyrite, chalcopyrite and arsenopyrite, distributed throughout their bulk. In some cases, these appear to be primary minerals, e.g. the arsenopyrite in section M5 which has crystallized around a phenocryst of felspar but which nevertheless appears to be earlier than the groundmass felspars which are arranged about it as in typical flow textures. Furthermore, in the Campbell's Nob dykes, small patches of galena are widely distributed throughout the dykes. The widespread occurrence of small quantities of sulphides in the dykes is suggestive of a close genetic relation between dykes and lodes.

(v) It was shown previously that the mineralizing solutions deposited sphalerite at a temperature greater than 350° C. It was also shown that the country rock was at a temperature probably less than 160° C. The high temperature of the mineralizing solutions appears to indicate that they were derived from some igneous agency, which according to field evidence could only be the lamprophyric magma.

REGIONAL METAMORPHISM OF GALENA. It was maintained above that the formation of galena lodes preceded the Tabberabberan Orogeny, which was responsible for the widespread and intense fracturing of granodiorite and lamprophyre dykes, and the folding of the Snowy River Volcanics. The evidence for this assertion lies in the fact that the galena at Deddick is invariably found to have suffered plastic deformation. Usually the deformation is not intense, giving rise to curved and distorted cleavage planes which are universal (HS nos. P1, P2). The plastic flow is sometimes well exhibited in the polished sections, where it is shown up by curving lines of cleavage pits in the galena. Sometimes a distinct banded texture due to plastic flow has arisen (HS nos. P1, P2). This widespread regional metamorphism of the galena is to be correlated with the widespread tectonic stresses developed during the Tabberabberan Orogeny.

Silver Content of Galena. A number of polished galena specimens were examined in order to determine the form in which the silver occurred. No trace of any silver bearing mineral (e.g. Tetrahedrite) was found, and it was concluded that the silver is carried in solid solution in the galena. Four tons of ore taken from various parts of the field when sampled and assayed at Port Pirie were found to contain 50·9% .Pb, 4·3% Zn and 15·8 oz/ton Ag. This corresponds to 27 oz. silver per ton of galena. Galena can carry up to 30 oz. to the ton of silver in solid solution (Edwards, 1947) and hence the Deddick galena must carry its silver in that form.

Oxidation. The mineral deposits possess very small zones of oxidation. In many places fresh galena occurs right at the surface. However, at the James and United Lodes, relatively small amounts of anglesite and cerrussite occur, whilst malachite and azurite are common in the Begelhole Lode. The smallness of the zones of oxidation is to be attributed to the extremely rapid dissection which the area is undergoing.

Mineral Zoning. An interesting feature of the mineral deposits is that mineral zoning is often well displayed, although the shoots of sulphide minerals possess only relatively small vertical depth ranges. The mineral zoning cannot be followed continuously, since the lodes have not been opened up by mining operations to any extent. However, in certain of the lodes which outcrop down very steep hillsides, and which have been opened up by cuts and adits at frequent intervals, the zoning can be recognized.

The best example is the Begelhole Lode. About 600 ft. above the river, a shaft follows the lode down for 50 ft. The sulphides here consist of pure galena. Some 300 ft. lower, an adit just above the road cuts the lode which consists of galena, with some massive chalcopyrite. Below the road, about 100 ft. above the river, another two adits show the lode to consist of a complex ore of sphalerite, chalcopyrite, pyrite and galena. On the opposite bank of the river, at the Mt. Deddick Mine, on the same lode, a shaft put down for 50 ft. encountered lode material rich in pyrite, together with some galena.

A vertical section of this lode consists of:

Galena
Chalcopyrite and galena
Chalcopyrite sphalerite and galena
Pyrite and galena.

This is in accord with the normal order of mineral zoning as given by Emmons (1924). Galena in depth tends to give way to chalcopyrite. Deeper still sphalerite comes in, and the deepest zone is mainly of pyrite. It should be pointed out, however, that galena is present in large amounts at all levels.

Another lode displaying zoning is the United, which outcrops down a very steep hillside At the top it consists of a quartz reef carrying small quantities of sulphides. Thirty feet lower this makes into a bulge of pure massive galena, and further down for another hundred feet, sphalerite begins to come in, increasing towards the bottom adit, where it is almost as abundant as galena.

The other lode displaying zoning is the James. The uppermost cuts show this lode to consist of quartz carrying some galena. One hundred feet lower down the lode consists of massive galena, and then for another 200 ft., although galena is by far the most common mineral, small amounts of sphalerite and chalcopyrite occur. Another 50 ft. lower, the lode consists of sheared granodiorite feebly mineralized with pyrite.

The lodes mentioned above are the only ones which have been appreciably exposed, and in each of them, vertical mineral zoning is displayed within a limited vertical extent of a maximum of 600 ft. in the case of the Begelhole Lode. There is no sign of a corresponding horizontal mineral zoning about any defined centre, however.

Economic Possibilities. There are two shoots of high-grade galena exposed in the James and United Lodes which might repay mining by a small syndicate. However, the main obstacle would be transport difficulties. The mines, although only 3 miles from a road (1½ miles directly across the Snowy River) are situated in rugged and inaccessible country. The value of the ore shoots may be insufficient to justify making a road in. Apart from the lodes mentioned none of the deposits opened up so far appears to be worth any attention. Any further work should be limited to the prospecting of gossans which have not as yet been opened up. Several of these have been noticed by the author.

### Structural Relations of Lodes and Dykes

The major features of the distribution of lodes and dykes have already been described (page , Fig. 2). Briefly these are:

(i) Dominant NW-NNW strike of both lodes and dykes. The strike is parallel to that of the Turnback Fault.

(ii) Concentration of lodes and dykes along a narrow zone south-west of the Turnback Fault. Lodes and dykes are absent on the other side of the fault. Density of lodes and dykes dies away gradually towards the south-west of the fault.

(iii) Occurrence in the zone nearest the fault of a series of E-W striking lodes, characteristically short, forming a set of complementary shears to the main N-W shear direction.

The significance of these facts must now be discussed. The fact that all the lodes and dykes occur in the down-thrown block south-west of the Turnback Fault, and that they increase in density as the fault is approached from the south-west, shows clearly that the fracture pattern of lodes and dykes has been controlled by the fault.

An hypothesis which seems at first sight attractive is that the dyke and lode fractures have been formed at the same time and by the same causes as the Turnback Fault, which is of Lower Devonian age. Subsequently, during the Upper Devonian, the fractures have been filled by dykes and lodes. Such an hypothesis is suggested by the exact parallelism of most dykes and lodes with the arcuate fault, the increase in density of dykes and lodes close to the fault, and by their dominant vertical dips. These fractures would therefore be regarded as subsidiary faults which have been partly responsible for sinking of the down-thrown block. There are two facts, however, which invalidate this hypothesis. The formation of complementary E-W shears close to the fault is not explained. It will be recalled that the dips of both sets of shears are close to vertical, and therefore the direction of the stress which caused the fracture pattern must have lain in the horizontal plane. According to the hypothesis mentioned above, the stress would lie mainly in the vertical plane. Furthermore, it would be expected that the direction of movement along these fractures would be vertical, whereas the great majority of slickensides indicate horizontal movement, a fact which was noticed by Ferguson (1899).

Two interpretations of the evidence are possible. The Turnback Fault might be regarded as having behaved as a surface of weakness in the stressed medium. In this case, the stress is to be regarded as normal, and according to the strain ellipsoid (Fig. 2) due to compression from the north-west, making an angle of about 25° with the Turnback Fault. The result has been the building up of a maximum amount of stress near the fault, causing greater intensity of shearing in the two complementary directions. Away from the fault the stress has been less, resulting in smaller fracture density and the suppression of one of the shear directions. It is probably because of the low angle of incidence (25°) of the plane of maximum stress with the plane of weakness in the granodiorite that the effects of the stress have not been manifested on the other side of the fault sufficiently to cause rupture.

An alternative interpretation would be to regard the fracture pattern as due to shearing stress in the horizontal plane developed along the Turnback Fault. This explains the more intense shearing close to the fault and the suppression of one of the directions of shear farther away. It does not, however, account satisfactorily for the complete absence of shearing north-east of the fault.

## Cainozoic–(Pliocene?)

### *Fluviatile Deposits*

Small patches of river gravels and sands occur beneath the basalt near the 8-mile post on the Deddick road, and on Mt. Turnback. Ferguson reports finding some thin interbedded clays containing leaf impressions. These gravels do not appear to be more than 20-30 ft. thick. They are not found beneath the basalt at Wulgulmerang. Their physiographic significance has already been commented upon.

### *Newer Basalt*

Basalt occurs on the plateau between the Buchan and Snowy Rivers in the central part of the Wulgulmerang area. A second large flow occurs at Gelantipy, stretching towards the south. It was formerly continuous with the Wulgulmerang sheet, but has now been separated due to dissection by Boundary Creek and its tributaries. A couple of small isolated outcrops at the same height (2,800-3,000 ft.) occur towards Black Mountain. These basalts are apparently the remains of a much more extensive sheet which sloped gently towards the south. The N-S ridge forming the Buchan River divide lies at a higher elevation than the basalt and marks the western limit towards which the flow originally extended. There is no such continuous containing ridge to the east, unless it is on the opposite side of the Snowy River. However, isolated inliers of rhyodacite protrude through the basalt quite frequently. The basalt at Wulgulmerang is usually less than 100 ft. in thickness, although it is thicker at Gelantipy. (See section in physiography.)

Small patches of basalt occurring at the Farm, Mt. Turnback and the 8-mile post are about 1,000 ft. lower than the Wulgulmerang flow. These are probably remnants of a formerly continuous flow which came down the Snowy River valley during an early stage of dissection, after the Pliocene uplift. The occurrence of river gravels underlying some of these basalts supports this interpretation.